AD-781 564

LOW-RADAR-CROSS-SECTION OH-6A HELICOPTER TAIL ROTOR BLADE

Sam Yao, et al

Fiber Science, Incorporated

Prepared for:

Army Air Mobility Research and Development Laboratory

April 1974

EUSTIS DIRECTORATE POSITION STATEMENT

Results of this effort show that a satisfactory LRCS tail rotor blade design was achieved, meeting the structural requirements of the OH-6A tail rotor blade and having a lower radar cross section than the original one.

The conclusions contained herein are concurred in by this Directorate. This concurrence is limited to technical accomplishment and does not imply the practicality of the proposed approach for application to current Army aircraft.

The technical monitor for this contract was Mr. George T. McAllister, Military Operations Technology Division.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

AD 781 564

REPORT DOCUMENTATION PAGE

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The design, fabrication, and testing results of a low-radar-cross-section (LRCS) filament-wound composite tail rotor blade for the OH-6A helicopter are reported herein. Two full-scale blades and four 12-inch-long blade sections were fabricated during the program. The blades and blade sections were all fabricated principally from Kevlar 49 roving/epoxy. The blades and blade sections all had sheets of microwave-absorbent materials laminated integrally with the windings to reduce the radar signature of the composite blade.

Block 20

The program objective of developing an LRCS blade with structural characteristics similar to the current metal OH-6A helicopter tail rotor blade using nonmetallic and radar-absorbent materials was met.

The four blade sections were used to evaluate the radar reflection characteristics of four different radar shielding configurations. These blade sections were tested for radar signature, and the raw test data were sent directly to the Army. The Army's evaluation of radar test data, along with FSI fabrication and structural analysis findings, formed the basis for selecting the radar shielding configuration to be used in the full-scale blades.

The first blade fabricated (S/N 001) and a metal blade were subjected to stiffness and natural frequency testing. Blade S/N 002 was sent directly to the Army for evaluation.

The composite blade was found to be very similar in weight, stiffness, and natural frequency to the metal blade in addition to being considerably more durable (resistant to handling damage).

The design concept is new for filament-wound composite blades; fabrication was found to be relatively simple and amenable to low-cost blade production.

PREFACE

This report was prepared by Fiber Science, Inc., a subsidiary of The Edo Corporation, in accordance with Contract DAAJ02-73-C-0041 issued by the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. Mr. George McAllister was the U. S. Army Program Technical Monitor.

The activities reported herein cover the period from March 1973 to December 1973. The FSI project engineer was Mr. David Wall.

The work was authorized by DA Task 1F262205AH8801.

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INTRODUCTION

Helicopter tail rotor blades fabricated from Kevlar 49/epoxy using the wet filament winding process offer the advantages of reduced cost, longer blade life, easier repair, and reduced radar cross section.

This report describes the results of a research and development program to design, analyze, fabricate, and perform limited testing on an LRCS all-composite OH-6A helicopter tail rotor blade.

The work performed herein was undertaken primarily to develop an LRCS helicopter rotor blade having structural characteristics similar to the existing metal blades.

Two blades and four 12-inch-long test sections were fabricated. The test sections were subjected only to radar testing, and the raw data were sent directly to the Army. No radar test data will be given in this report. One of the full-scale blades was subjected to limited structural and dynamic testing and the second blade was sent to the Eustis Directorate for evaluation.

Reported herein are the criteria, design, fabrication, and structural and dynamic test results. Radar test results will be reported by the Radar Target Scatter Facility (RATSCAT), 6585th Test Group (RX), Holloman AFB, New Mexico, when available.

DETAIL DESIGN

GENERAL CONFIGURATION

A tail rotor blade using principally Kevlar 49/epoxy in conjunction with radar-absorbent materials was designed and constructed to the general configuration delineated in Figure 1. The external geometry and attachment are identical to the current OH-6A helicopter metal tail rotor blade. The airfoil shape is an NASA 0014 based on a chord length of 4.81 inches.

DESIGN CRITERIA

The design goal was to match the geometry, stiffness, strength, center of gravity, and dynamic characteristics of a standard metal OH-6A helicopter tail rotor blade using materials and techniques to minimize its radar cross section (RCS).

The limit design loads and cross-sectional properties at blade Stations 7.5, 11.6, and 25.5 are shown in Table I. Ultimate loads are equal to 1.5 times the limit loads.

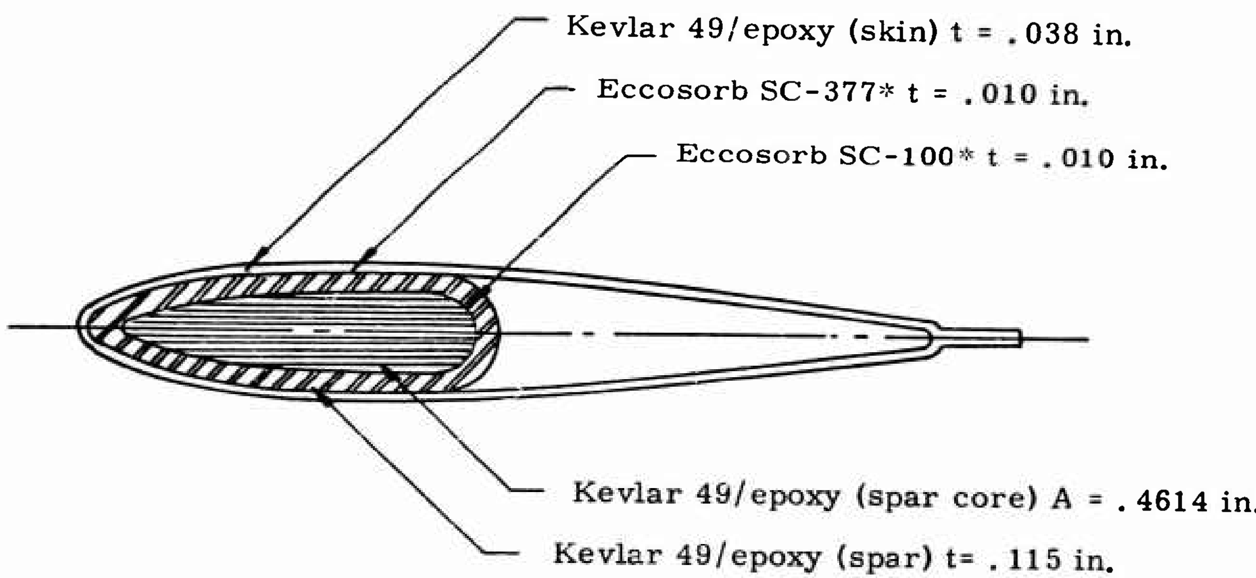
TABLE I. LOAD AND STIFFNESS CRITERIA

	Station 7.5	Station 11.6	Station 25.5
Load Data (Limit)			
Speed	3450	3450	3450
M_{fl}, in.-lb	1820	1365	0
M_{ch}, in.-lb	210	294	0
CF, lb	8906	7972	0
Cross-Section Properties			
W, lb/in.	.0492	.0687	.0425
EA, 10^6 lb	5.0988	4.1267*	2.7067
EI_{fl}, 10^6 lb-in.^{2}	.7193	0.2545	0.1306
EI_{ch}, 10^6 lb-in.^{2}	.7193	4.389	3.357

* Spar tube only.

The measured weight and center of gravity of the metal blade are:

$$\left.\begin{array}{lcl} \text{Weight} & = & 2.05 \text{ lb} \\ \text{Dimension a} & = & 13.06 \text{ in.} \\ \text{Dimension b} & = & 1.10 \text{ in.} \end{array}\right\} \text{See Figure 2}$$



*Microwave-absorbent material

Figure 1. Typical Cross Section of OH-6A Helicopter (LRCS) Tail Rotor Blade.

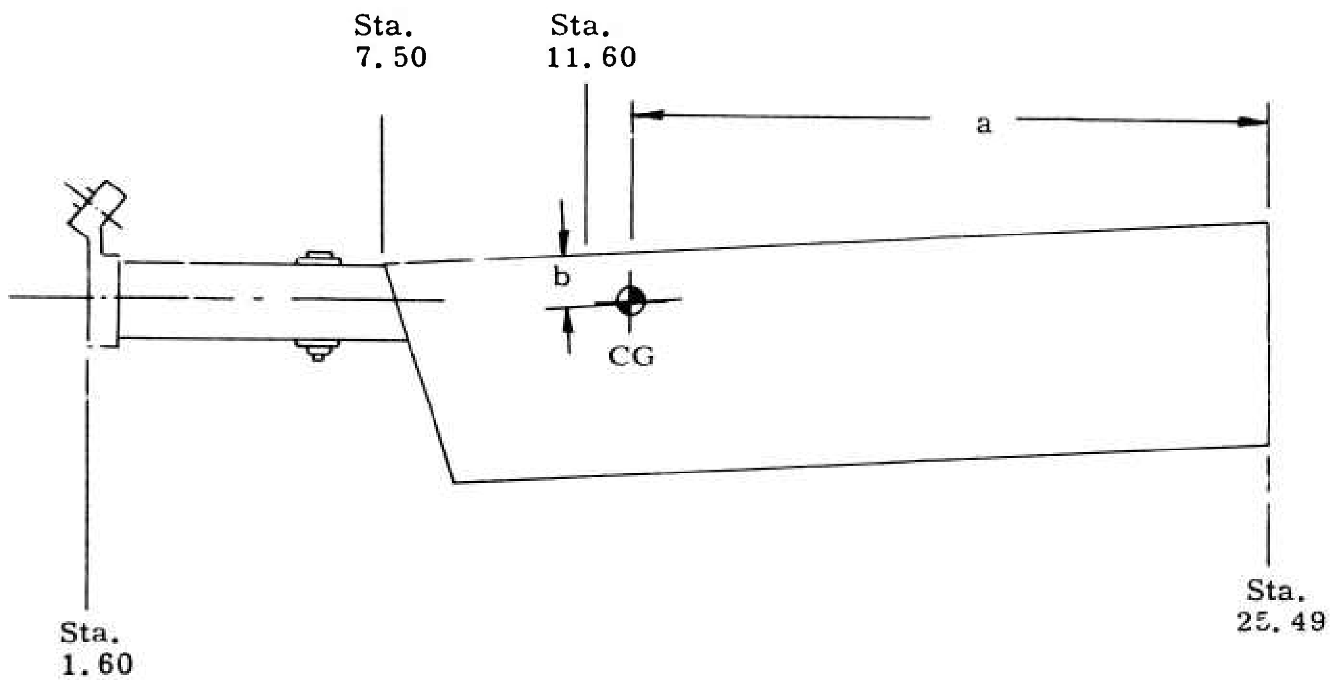


Figure 2. Plane View of OH-6A Helicopter Tail Rotor Blade Showing Stations and Center of Gravity Location.

MATERIAL SELECTION

Introduction

The fibers and resin (Kevlar 49/epoxy) were selected in accordance with the contract requirements, prior experience, and on the basis of radar reflectivity. The radar-absorbent materials were selected based on compatibility with blade design and the fabrication process. To aid in selecting the radar-absorbent materials and to substantiate the blade design, 12-inch-long blade sections (each using a different configuration for radar shielding) were fabricated and tested to determine relative values of radar reflectance.

Kevlar 49/Epoxy

The characteristics of Kevlar 49 and the epoxy resin (APCO 2434/APCO 2345 7.5 phr, product of Applied Plastics Company) are summarized in Table II.

TABLE II. RAW MATERIAL PROPERTIES

Property	Kevlar 49	Epoxy
$E_{//}$, 10^6 psi	19.0	0.5
$E_{\perp}$, 10^6 psi	1.42	0.5
G, 10^6 psi	0.27	0.18
F_{tu}, psi	400,000	9,500
F_{cu}, psi	70,000	15,000
ρ, lb/in.^{3}	0.0524	0.0412

The composite properties of the Kevlar 49/epoxy are:

Fiber Volume Ratio $V_f = .50$

Density $\rho_c = .50 \times .0524 + .50 \times .0412 = .0468$ lb/in.^{3}

The following composite material properties of the blades' skin, spar, and spar longo materials were calculated using FSI computer programs P-II, P-III, and STREN.

Skin (Kevlar 49/Epoxy)

$\alpha = \pm 20^\circ$

$V_f = .50$

$E_x = 6.335 \times 10^6$ psi

$E_y = 0.8313 \times 10^6$ psi

$G = 1.189 \times 10^6$ psi

$F_x = 81,900$ psi

$F_y = 4,000$ psi

<u>Spar</u> (Kevlar 49/Epoxy)

80% at $\alpha = \pm 20^\circ$, 20% at $\alpha = 90^\circ$

$V_f = .50$

$E_x = 6.059 \times 10^6$ psi

$E_y = 2.618 \times 10^6$ psi

$G = 0.996 \times 10^6$ psi

$F_x = 121,100$ psi

$F_y = 41,900$ psi

$F_{xy} = 25,000$ psi *

<u>Spar Longos</u> (Kevlar 49/Epoxy)

$\alpha = 0^\circ$

$V_f = .50$

$E_x = 9.750 \times 10^6$ psi

$E_y = .946 \times 10^6$ psi

$G = .2239 \times 10^6$ psi

$F_x = 200,000$ psi

$F_y = 2,000$ psi

---

* Estimated

Radar-Absorbent Materials

The characteristics of the microwave absorbers used in the program are shown in Table III.

TABLE III. MICROWAVE ABSORBER CHARACTERISTICS SUMMARY

Property	Material *				
	SC-100	SC-377	VF-10	VF-30	LS-22
Thickness, in.	.01	.01	.01	.03	.125 to .750
Density, lb/in.^{3}	.0694	.0694	.0694	.0694	.0029
Strength	N. A.	N. A.	N. A.	N. A.	Soft Foam
Loss Factor(K'')**	45-65	15-25	-	-	-
ohm-cm	-	-	-	-	2.5K
ohms/sq	100	377	377	130	-
Basic Composition	Carbon bonded to fabric		Carbon in flexible plastic		Foam

* Product of Emerson & Cuming, Inc.
** 8.6 GHz

SAMPLE EVALUATION

The purpose of this phase was to evaluate the relative radar reflectivity of four candidate blade configurations. Full-scale 12-inch-long sections were fabricated and tested (see Figures 3 through 7). The radar reflection data were evaluated by the Army, and the prototype blades identical to configuration No. 4 were fabricated (see Figure 7).

COMPONENT DESIGN

Skin

The skin was made up of two layers of Kevlar 49/epoxy helically wound at ± 20 degrees and one ply of SC-377 microwave-absorbent material. The skin was bonded to the spar assembly (secondary bond) over its full length. A ± 20-degree winding angle was chosen because it yielded material properties, axial and shear moduli, which best satisfied the blade stiffness criteria. Figures 8 and 9 show a theoretical plot of moduli and strength versus winding angle for Kevlar 49/epoxy.

Figure 3. The Four Radar Test Sections.

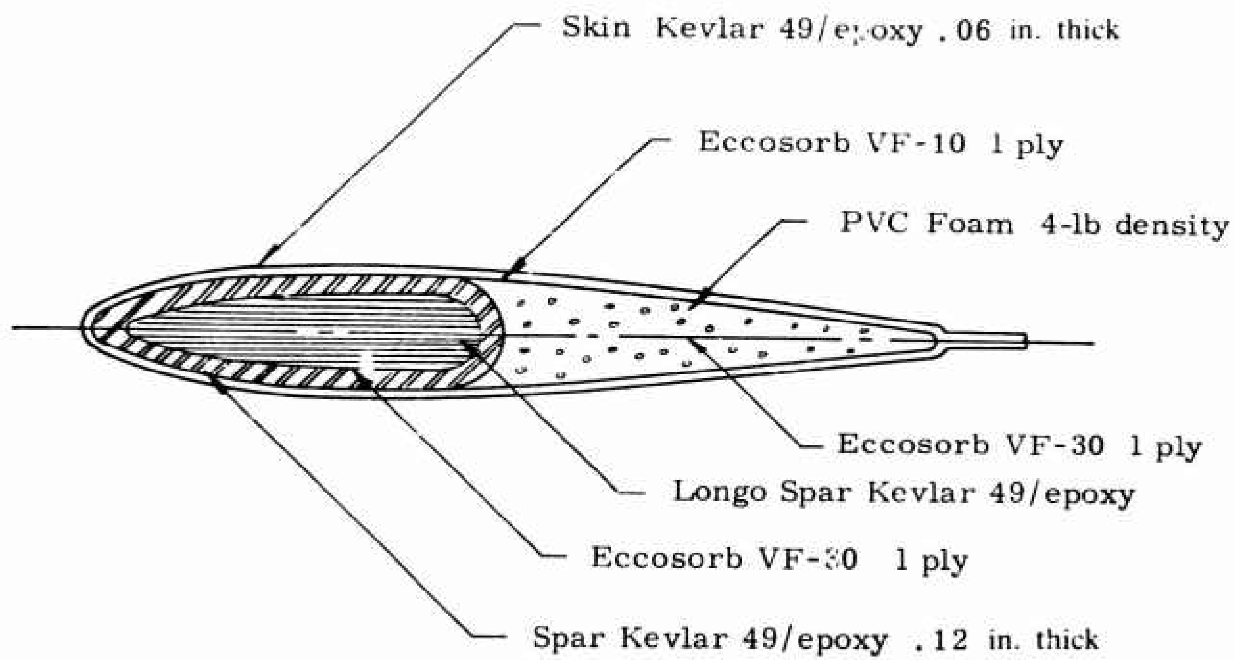


Figure 4. Radar Test Section Configuration No. 1.

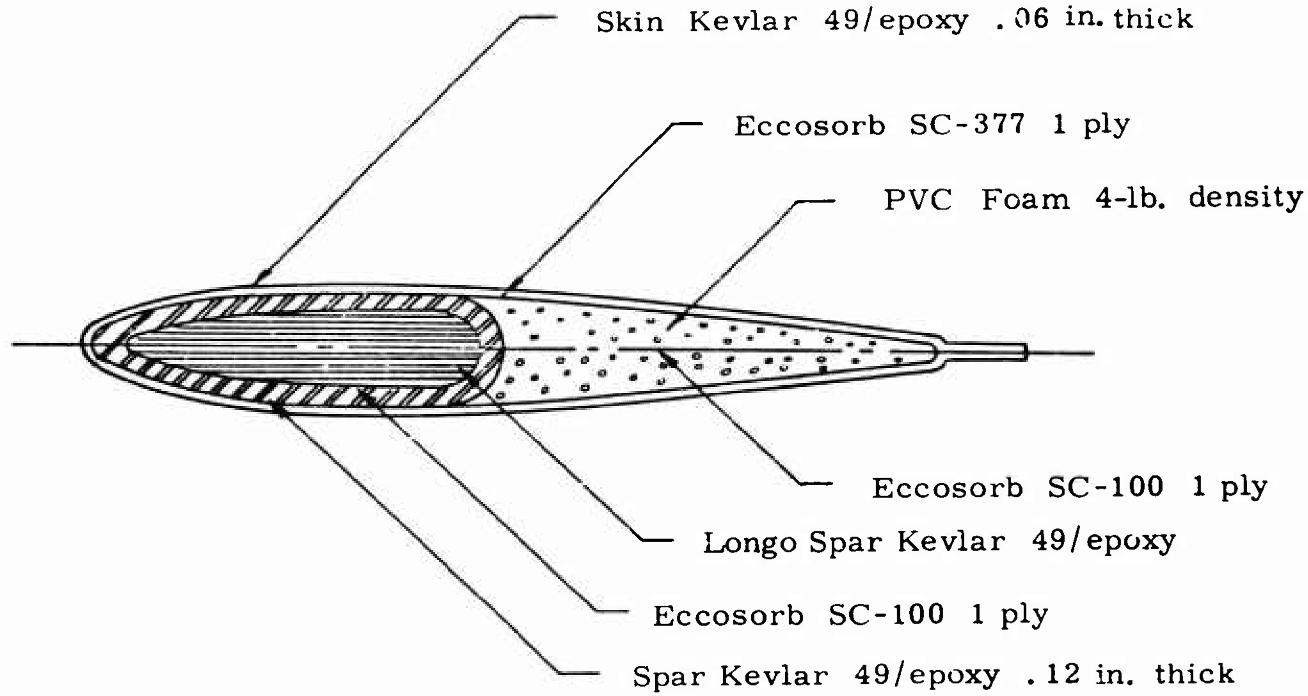


Figure 5. Radar Test Section Configuration No. 2.

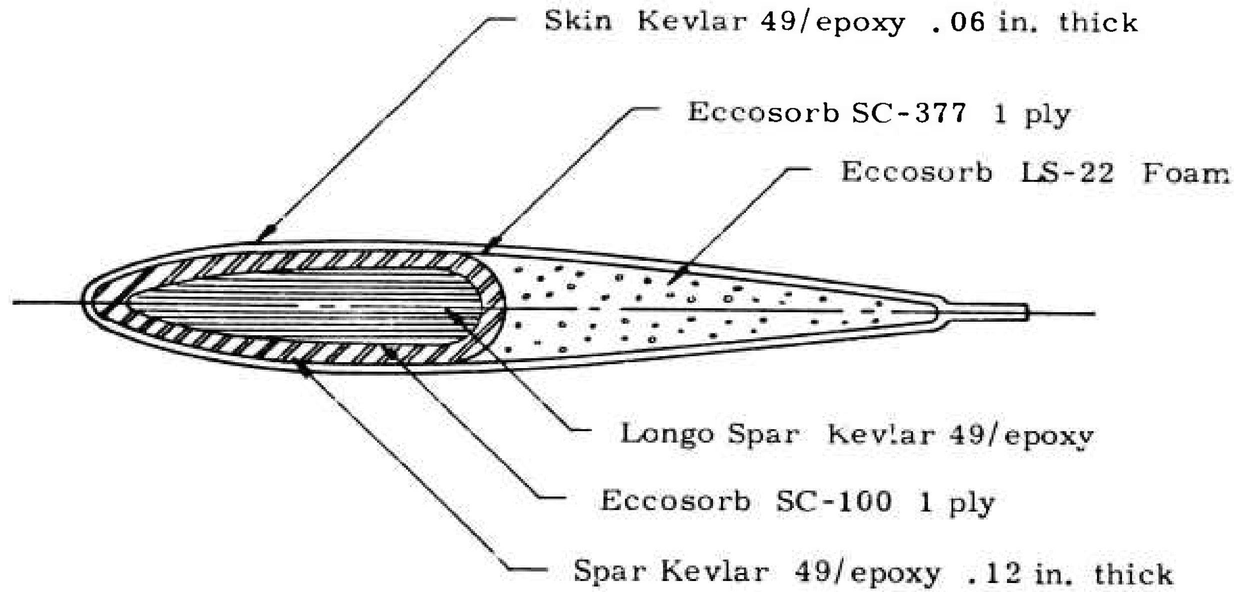


Figure 6. Radar Test Section Configuration No. 3.

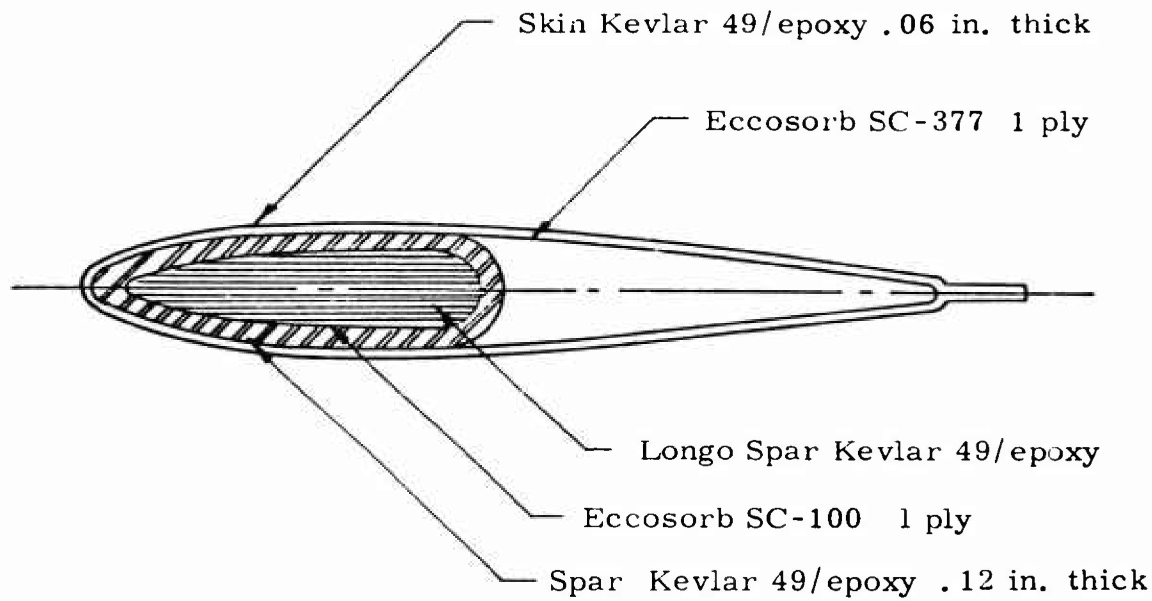


Figure 7. Radar Test Section Configuration No. 4.

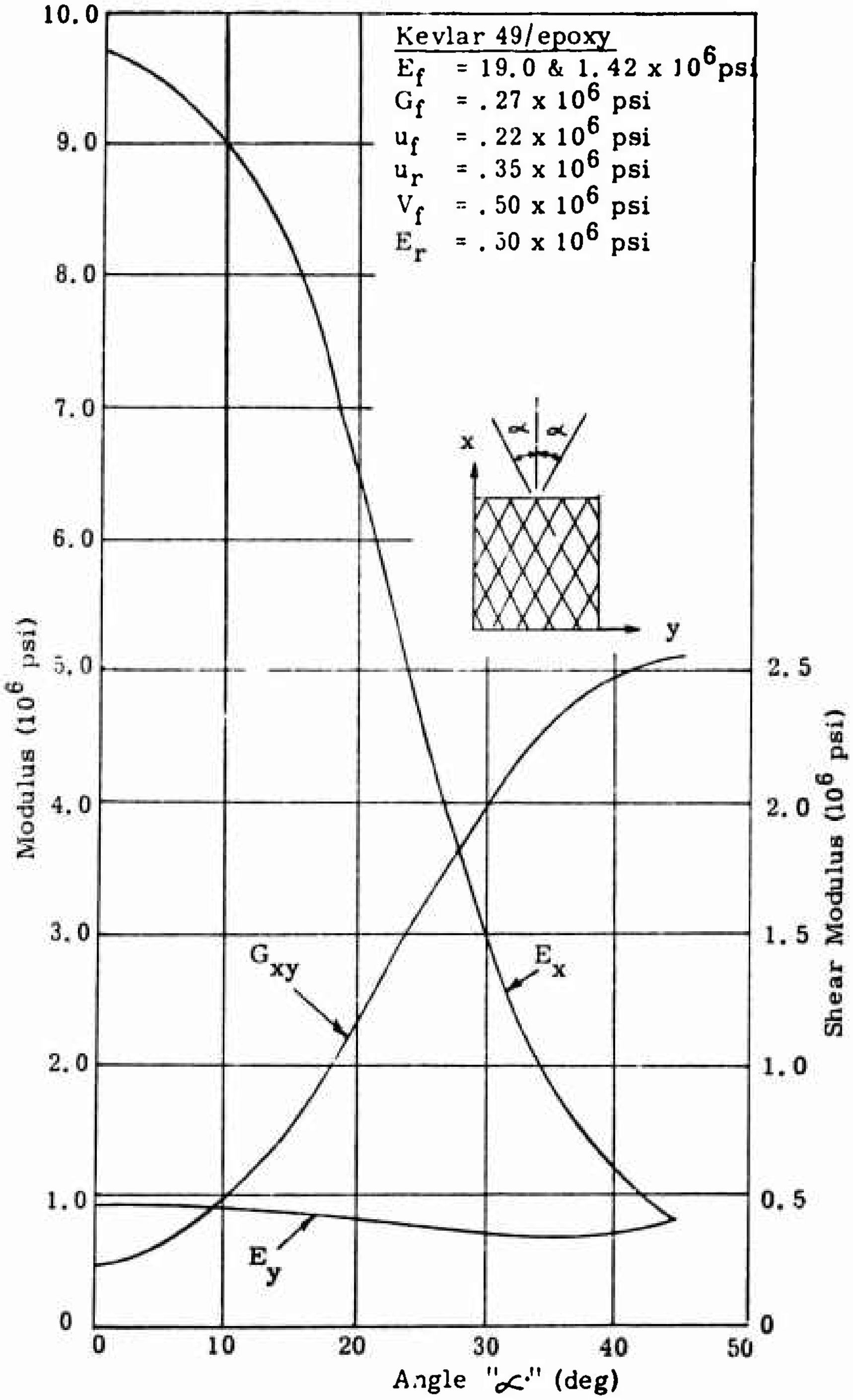


Figure 8. Modulus Versus Winding Angle, Kevlar 49/Epoxy.

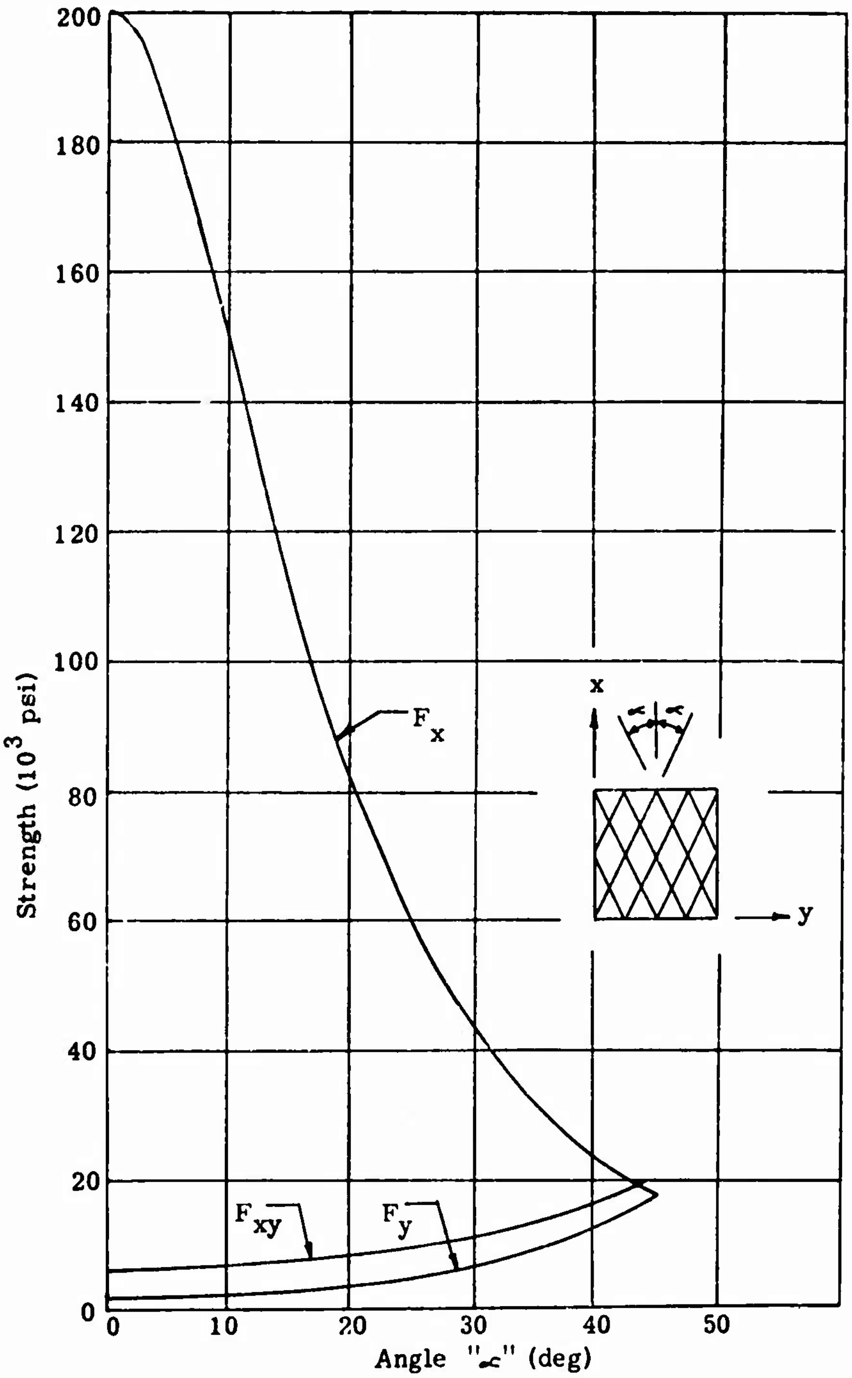


Figure 9. Strength Versus Winding Angle, Kevlar 49/Epoxy.

Spar

The spar assembly consisted of an inner core of unidirectional (longo) Kevlar 49/epoxy windings which were wrapped around a metallic fitting in the root end area. Encompassing the longo material is a tube consisting of one ply of SC-100 microwave absorber overwound with six helical layers wound at ± 20 degrees and 2 circumferential plies of Kevlar 49/epoxy. The band density for the helical and circumferential windings was calculated to yield thicknesses of .092 and .023 inch respectively. The spar (longo and tube windings) was assembled wet and configurated and cured in a female mold. The transition area of the spar was configurated using several glass fabric/epoxy precured laminate fillers. These fillers were used primarily to control configuration and were not recognized in the analysis.

The longo windings and the fitting they wrap around were designed to carry the full CF loading, and the tube windings were designed to carry the full root end bending and torsion loads. Again, the winding angles were chosen to yield the desired material properties.

The spar was constant cross section except in the root end transition area where the metal blade has a tapered spar. This difference will cause the CG of the composite blade to be slightly further outboard.

Ribs

Two Style 181 glass fabric/epoxy laminated ribs each .06 inch thick were secondary bonded - one at the tip and the other at the root end of the skin. These ribs served both to seal the open ends of the skin aft of the spar and to carry shear loads to the spar.

Miscellaneous

The internal bearings and arm assembly were purchased items currently used on the metal blade and were bonded in place.

FABRICATION OF BLADES

Two OH-6A tail rotor blades and four 12-inch-long radar test sections were fabricated during the program. The tooling design and manufacturing methods were oriented to the limited quantity of prototype blades and sections of blades to be built. The same tooling was used to fabricate the two prototype blades and four blade sections.

TOOLING

The tool masters and tools fabricated for this program are

1. Blade skin mold master: see drawing FSHT-726 and Figure 10 (Metal reinforced plaster).

2. Blade skin mold; see drawing FSHT-727 and Figure 11 (glass reinforced plastic).

3. Spar mold; see drawing FSHT-728 and Figure 12 (glass reinforced plastic).

4. Spar assembly and winding mandrel; see drawing FSHT-729.

5. Spar mandrel (steel pipe).

6. Skin mandrel (air-inflated plastic tube).

7. Rib molds (plaster).

Note: The spar mold master was fabricated from a plaster-filled thin-walled plastic tube configurated in the blade skin mold.

DETAILED PART FABRICATION

The blade skin, spar, and spar core (longo material) were all fabricated by the filament-winding/post-deforming process developed at FSI.

The skin material was fabricated by first wrapping a resin-impregnated ply of radar-absorbent material around an air-inflated plastic mandrel and then covering it with two layers of wet helical windings. Prior to curing, the end domes of the wound tube were removed (cut off) and the plastic mandrel and skin material placed into the skin mold (see Figure 13), bagged, and cured using autoclave pressure. The skin was rough trimmed and set aside for later assembly with the spar.

Prior to starting fabrication of the spar, the spar fillers were laminated, from Style 181 glass fabric/epoxy, and machined to dimension. Also, the longo pin and bearing plate (Ref. Drawings 56-B-010 and 56-B-011)

Figure 10. Internal Structure of Blade Skin Mold Master.

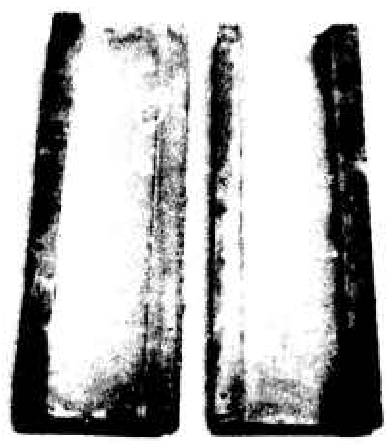


Figure 11. Blade Skin Mold.

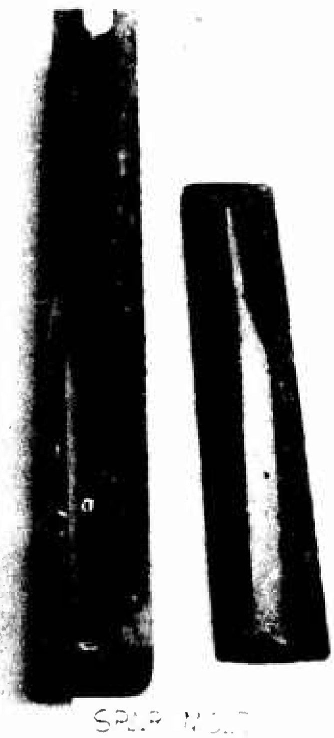


Figure 12. Blade Spar Mold.

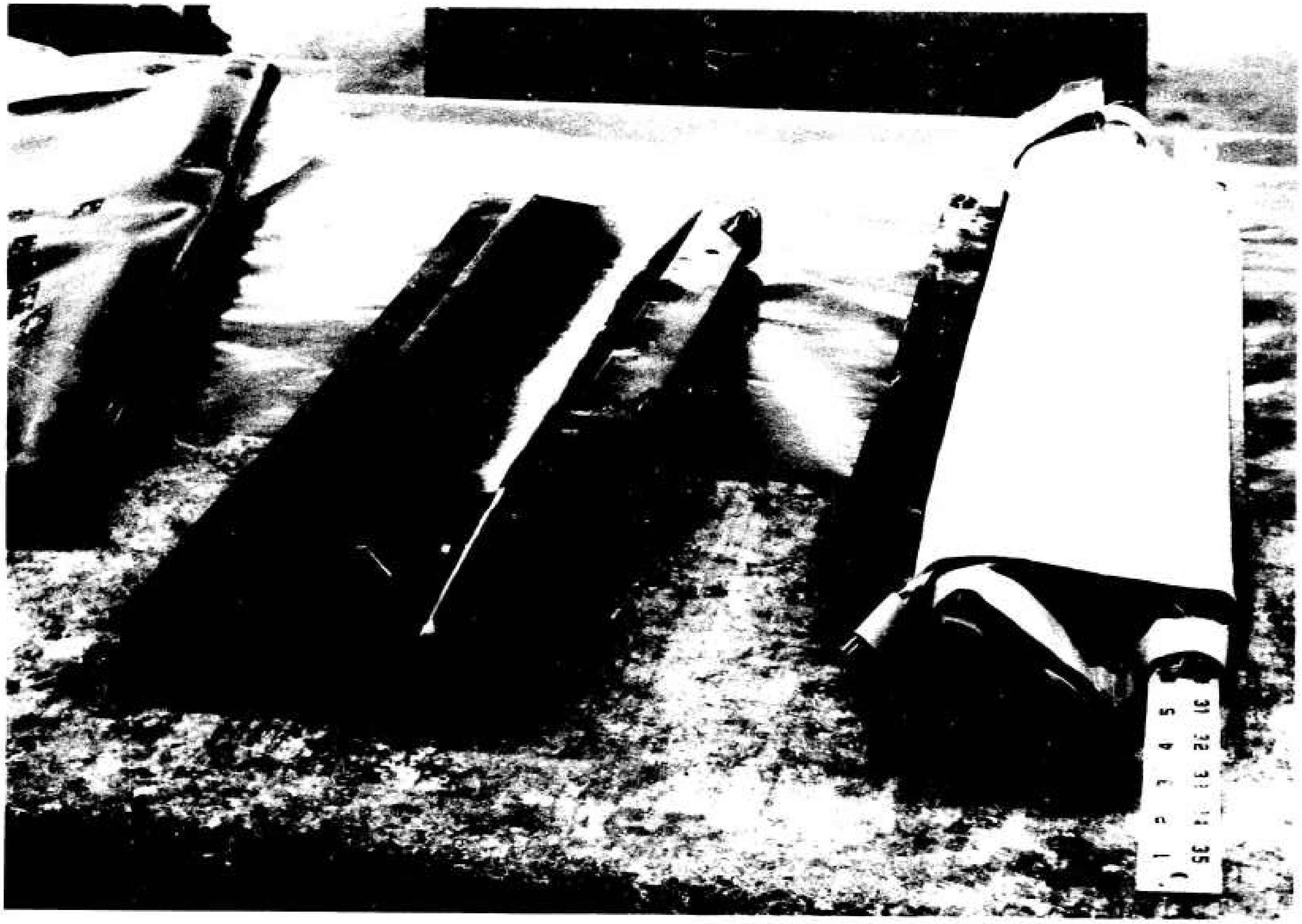


Figure 13. Wet Wound Skin Being Positioned in the Skin Mold.

were made using conventional metal fabrication techniques (see Figure 14). The spar core was wet wound using the spar assembly mandrel to support the bearing plate and longo pin (see Figure 15).

The spar tube was first wet wound over a radar-absorbent material which in turn was wrapped over a paper-covered hard mandrel. The outside hoop winding was temporarily terminated near the root end fitting. The tube ends were cut off and the spar tube was removed from the mandrel with the paper acting as a carrier. The uncured spar core material was then slipped inside the uncured spar. The paper carrier inside the spar tube was removed and the hoop winding in the root end area applied (see Figure 16). The still uncured spar assembly was then placed in the spar mold, configurated, and cured (see Figure 17).

The closing ribs were laminated, vacuum bagged, and cured using conventional fiberglass laminating techniques.

The skin, spar, closing ribs, bearings, and pitch arm were assembled using a room temperature setting/high temperature postcuring epoxy adhesive. Figure 18 shows the completed blade.

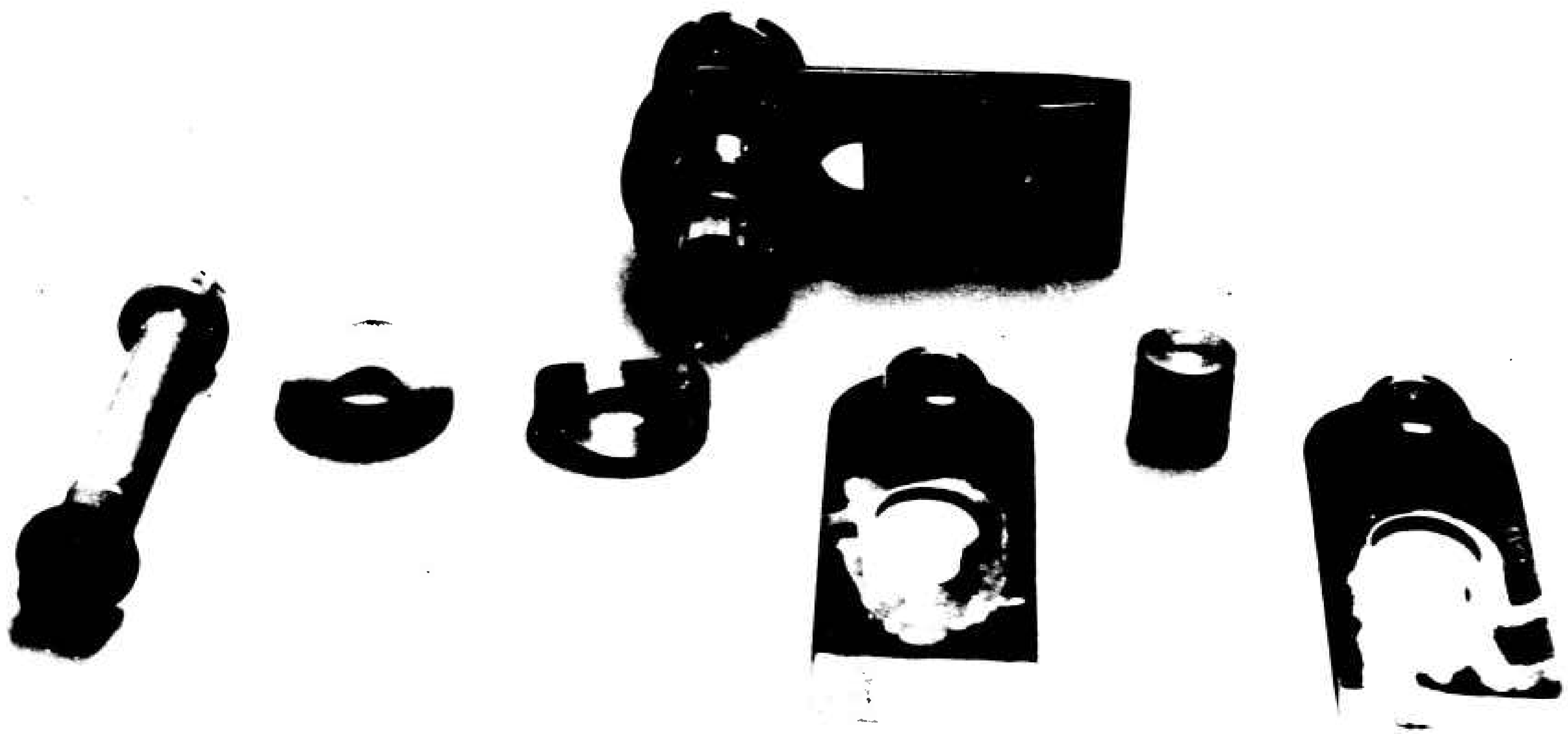


Figure 14. Bearing Plate Hardware.

Figure 15. Spar Core Assembly.

Figure 16. Application of Hoop Windings in the Spar Root End Area.

Figure 17. Spar Assembly as Molded.

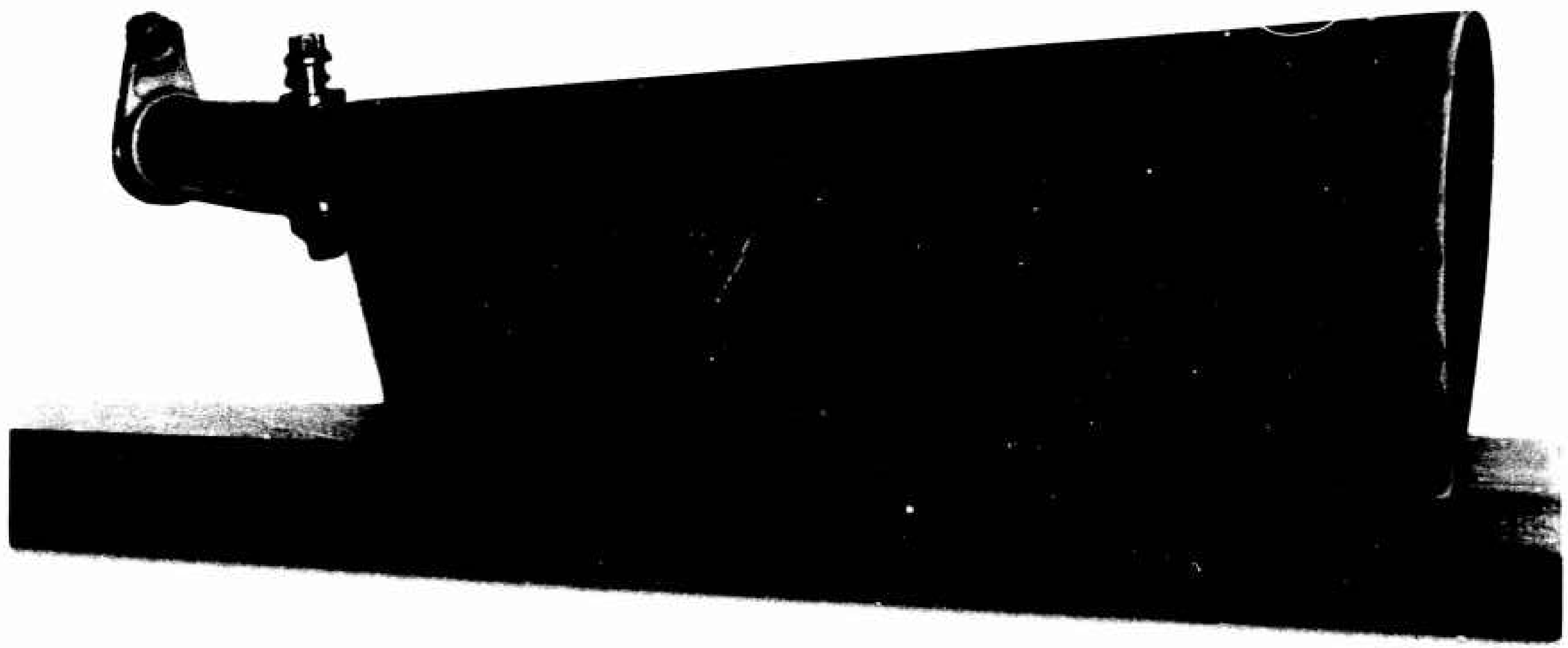


Figure 18. Completed OH-6A Helicopter Composite Tail Rotor Blade.

RESULTS

FABRICATION

Two prototype OH-6A helicopter tail rotor blades and four 12-inch-long blade sections were successfully fabricated by the wet filament-winding/ post-deforming process. The significant results of the fabrication are:

1. A process of encapsulating unidirectional wet-wound fibers inside a wet-wound spar and post deforming the assembly prior to curing was demonstrated.

2. The actual fabrication was found to be much easier than anticipated.

3. The process used in the fabrication of the spar assembly should have application to helicopter main rotor blades as well as tail rotor blades.

4. Microwave-absorbent material with the skin and spar windings was incorporated without difficulty.

The inspection report for blade S/N 001 is shown in Table IV, and the weight and cg of both the metal and composite blade are shown in Table V. In some cases there are deviations from the drawings, however these will have very little effect on the stiffness, dynamic, or radar cross sectional characteristics.

TABLE IV. INSPECTION REPORT - S/N 001

DATE 10/18/73

PART NUMBER 56-XB-001-1

PART NAME Tail Rotor Blade

PURCHASE ORDER NO.

SHT 1 **OF** 1

INSPECTOR Myron Cole

INSPECTED FOR Rework ☐ New ☒ **HEAT TREATED** Yes ☐ No ☐

TOOL DWG DIM	ACTUAL DIM	DIM ACCEPT. Yes	DIM ACCEPT. No	REMARKS
$1.127 ^{+.003}_{-.000}$	1.124 - 1.129			
.125 ± .03	.110			
2.90 ± .06	2.900			
.19	-			Overwrapped
23.89	23.912			
.048 Skin	.046 - .049			Ck'd. in Detail
4.65	4.650			
16.57	16.550			
15° ± 30'	15°			
3° 18'	2° 55'			
1.78	1.830			
5° 20' ± 0° 20'	8° 25'			
4.75	4.730 - 4.750			
.38				
1.500 Dia.	1.535			
1.250 Dia.	1.236 - 1.238			
2.04 lbs. Max.	2.07 lb. (S/N X-001)			Less Bolt & Nut
	2.17 lb. (S/N X-002)			

Note: One facing of S/N X-002 blade has concave area approximately 1" wide x 8" long.

TABLE V. WEIGHT AND CENTER OF GRAVITY LOCATIONS			
Blade	Total Weight (lb)	Center of Gravity	
		Station	Chordwise
Metal	2.05	12.43	1.10
S/N 001	2.07	12.79	1.15
S/N 002	2.17	N.A.	N.A.

TESTING

Composite blade S/N 001 and a Government-furnished metallic OH-6A tail rotor blade were subjected to static and dynamic testing as follows.

Stiffness tests were conducted by securing the root ends of the blade in a fixture and measuring the blade deflections and rotations at blade Stations 13.60 and 25.49 (see Figures 19 through 21). The tip loads were 20 pounds, 40 pounds, and 100 inch-pounds for the flapwise, chordwise, and torsional deflection measurements.

Table VI shows a comparison of blade stiffnesses determined by analysis and calculated based on measured deflections and rotations of the blade under known loads.

TABLE VI. BLADE STIFFNESS COMPARISON				
Property ($in.-lb^2$)	Metal Blade		Composite Blade	
	Calculated	Experim. *	Calculated	Experimental *
EI_{fl}, 10^6	.2545 to .1306	.211	.271	.200
EI_{ch}, 10^6	4.389 to 3.357	4.05	9.21	2.16
GK, 10^6	N.A.	.58	.16	.23

* Measured beam deflections and rotations were reduced to stiffnesses assuming the blade to be a simple cantilever beam and do not account for the blade twist.

The natural frequencies in the flapwise and chordwise modes were determined by attaching the blade root end rigidly to the head of a shaker (see Figures 22 and 23). The torsional natural frequency was determined by attaching the blade root end rigidly to a rotatable blade which in turn was oscillated by a shaker (see Figure 24). Table VII summarizes the blades' natural frequencies.

TABLE VII. BLADE NATURAL FREQUENCY COMPARISON		
Mode	Metal Blade (Hz)	Composite Blade (Hz)
First Flapwise	65	64
Second Flapwise	236	228
First Chordwise	84	73
Second Chordwise	509	472
First Torsional	281	253

The node locations, excitation, and tip displacements measured during dynamic testing are shown in Table VIII.

TABLE VIII. DYNAMIC TEST RESULTS

	Excitation DA	Tip DA	Node Loc. *	Frequency Hz
Metal Blade				
First Flapwise	.038	.90	-	65
Second Flapwise	-	-	5.16	236
First Chordwise	.038	.40	-	84
Second Chordwise	-	-	5.11	509
Torsional	-	-	-	281
Composite Blade				
First Flapwise	.038	.50	-	64
Second Flapwise	-	-	6.1	228
First Chordwise	.038	.40	-	73
Second Chordwise	-	-	6.6	472
Torsional	-	-	-	253

* Distance from blade tip end

Figure 19. Composite Blade Test Installation, Flapwise Stiffness Test.

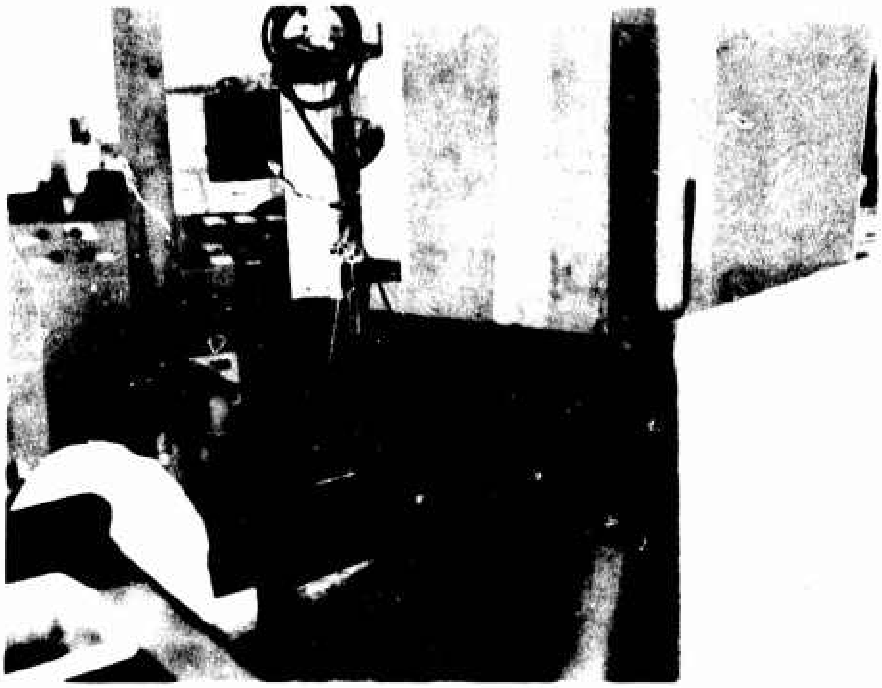


Figure 20. Composite Blade Test Installation, Chordwise Stiffness Test.

Figure 21. Composite Blade Test Installation, Torsional Stiffness Test.

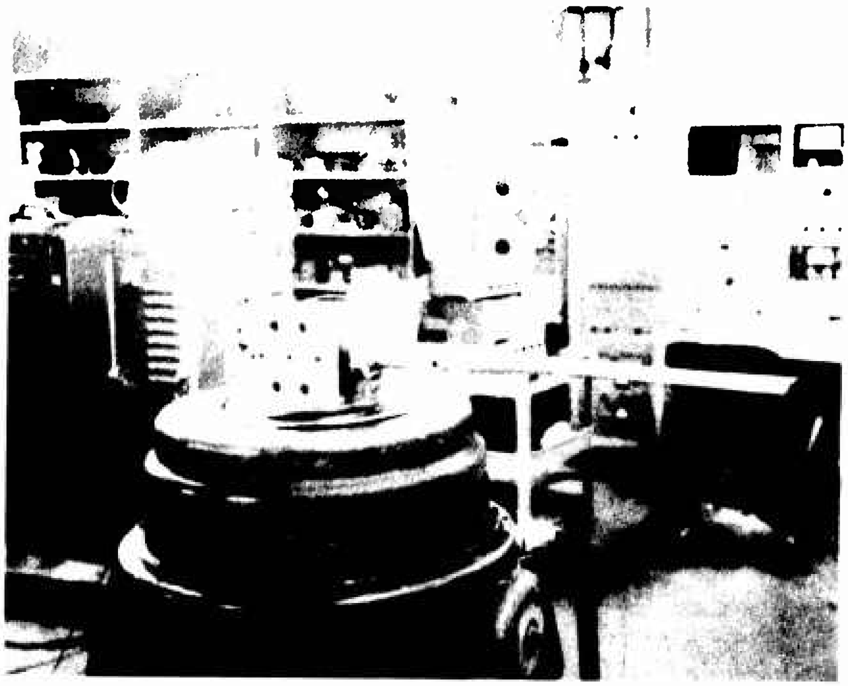


Figure 22. Composite Blade Test Installation, Flapwise Natural Frequencies Tests.

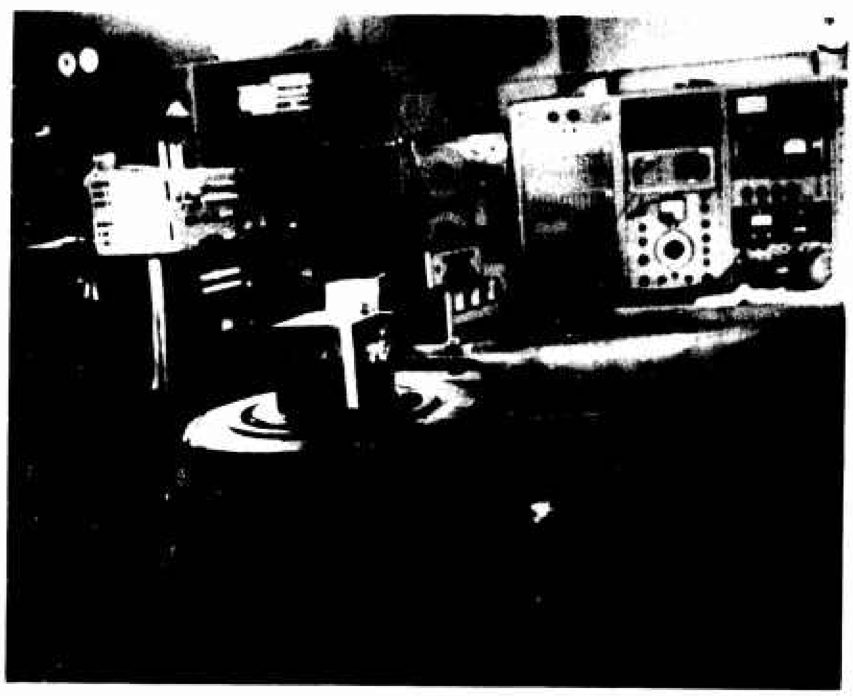


Figure 23. Composite Blade Test Installation, Chordwise Natural Frequencies Tests.

Figure 24. Composite Blade Test Installation, Torsional Natural Frequency Test.

CONCLUSIONS

It is concluded that:

1. Two filament-wound OH-6A helicopter rotor blades were constructed, demonstrating the feasibility of the filament winding techniques. This concept should be adaptable to both tail and main rotor blades.

2. Incorporation of microwave-absorbent material in with filament windings of Kevlar 49/epoxy was demonstrated.

3. Blade fabrication was simpler than anticipated.

4. A new unique root end attachment concept was conceived and demonstrated.

APPENDIX I

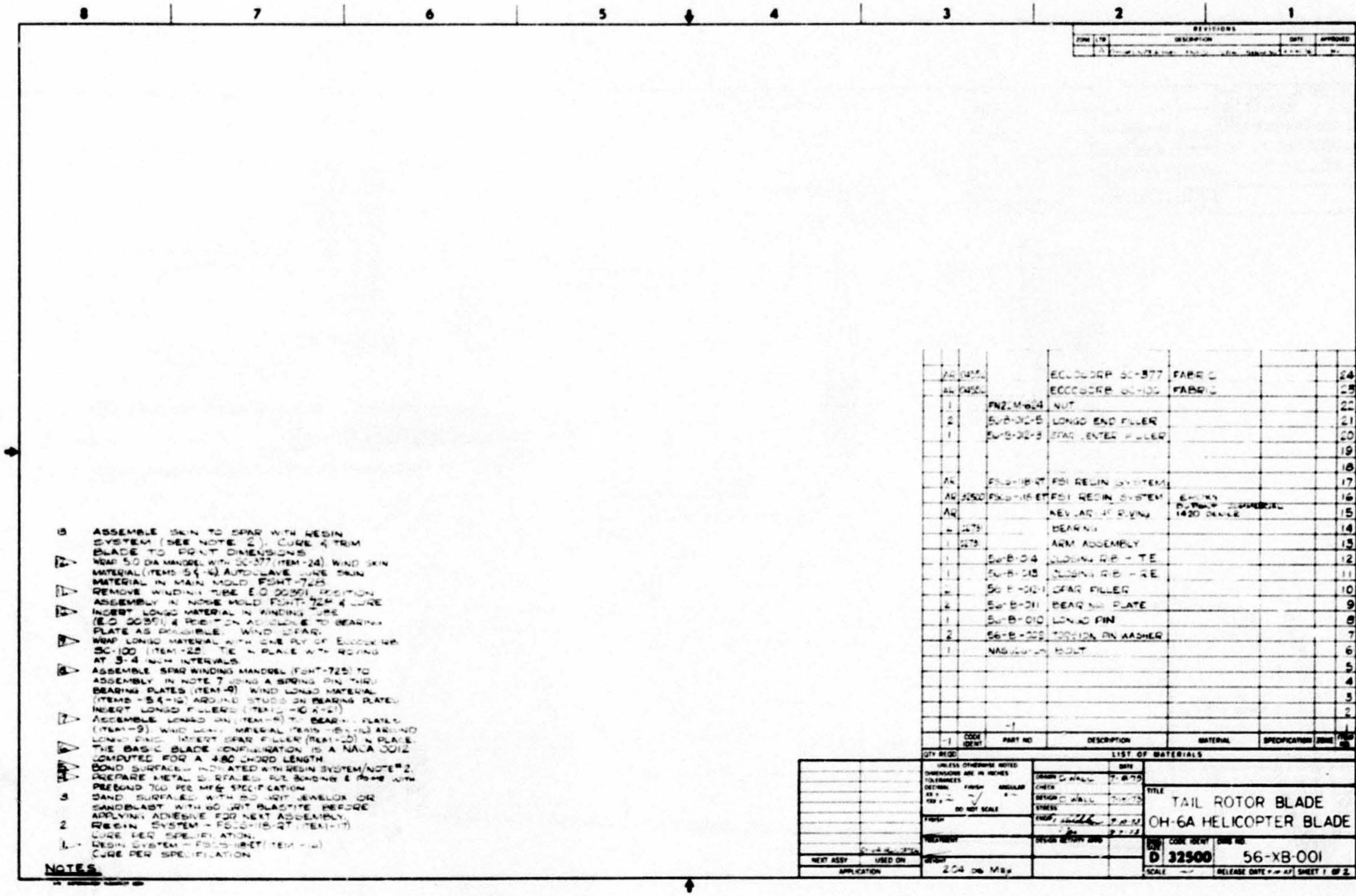
DRAWINGS

This appendix contains the following shop drawings:

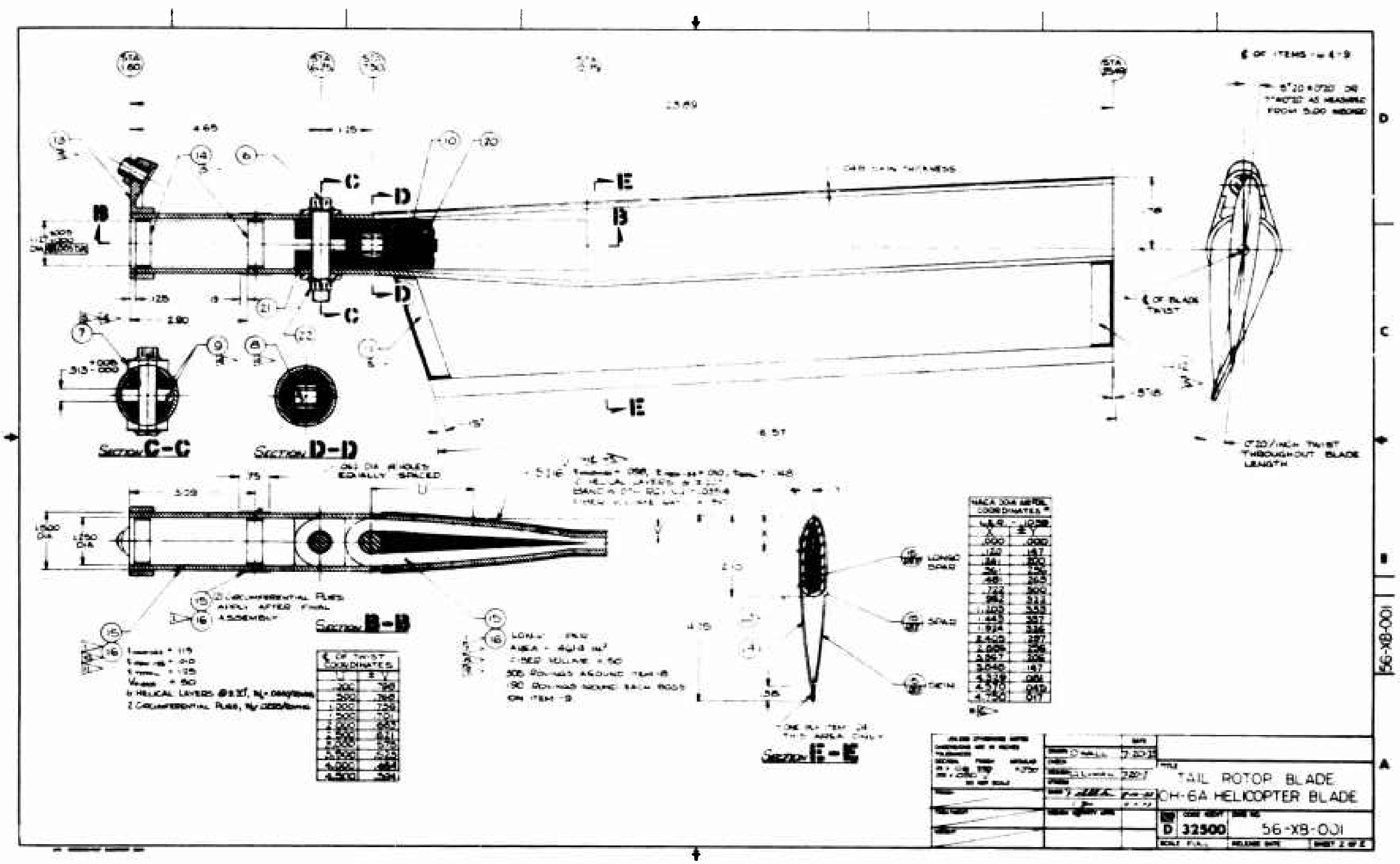
Drawing Number	Title
56-XB-001	Tail Rotor Blade OH-6A Helicopter Blade
56-B-009	Torsion Pin Washer
56-B-010	Longo Pin
56-B-011	Bearing Plate
56-B-012	Spar Fillers - OH-6A Tail Rotor Blade
56-B-013	Closing Rib - R. E.
56-B-014	Closing Rib - T. E.
FSHT-726	Master OH-6A Tail Rotor
FSHT-727	Main Mold OH-6A Tail Rotor Blade
FSHT-728	Nose OH-6A Tail Rotor Blade
FSHT-729	Winding Mandrel
E. O. 00391	Winding Tube (Referenced in Dwg. 56-XB-001)

SPECIFICATION

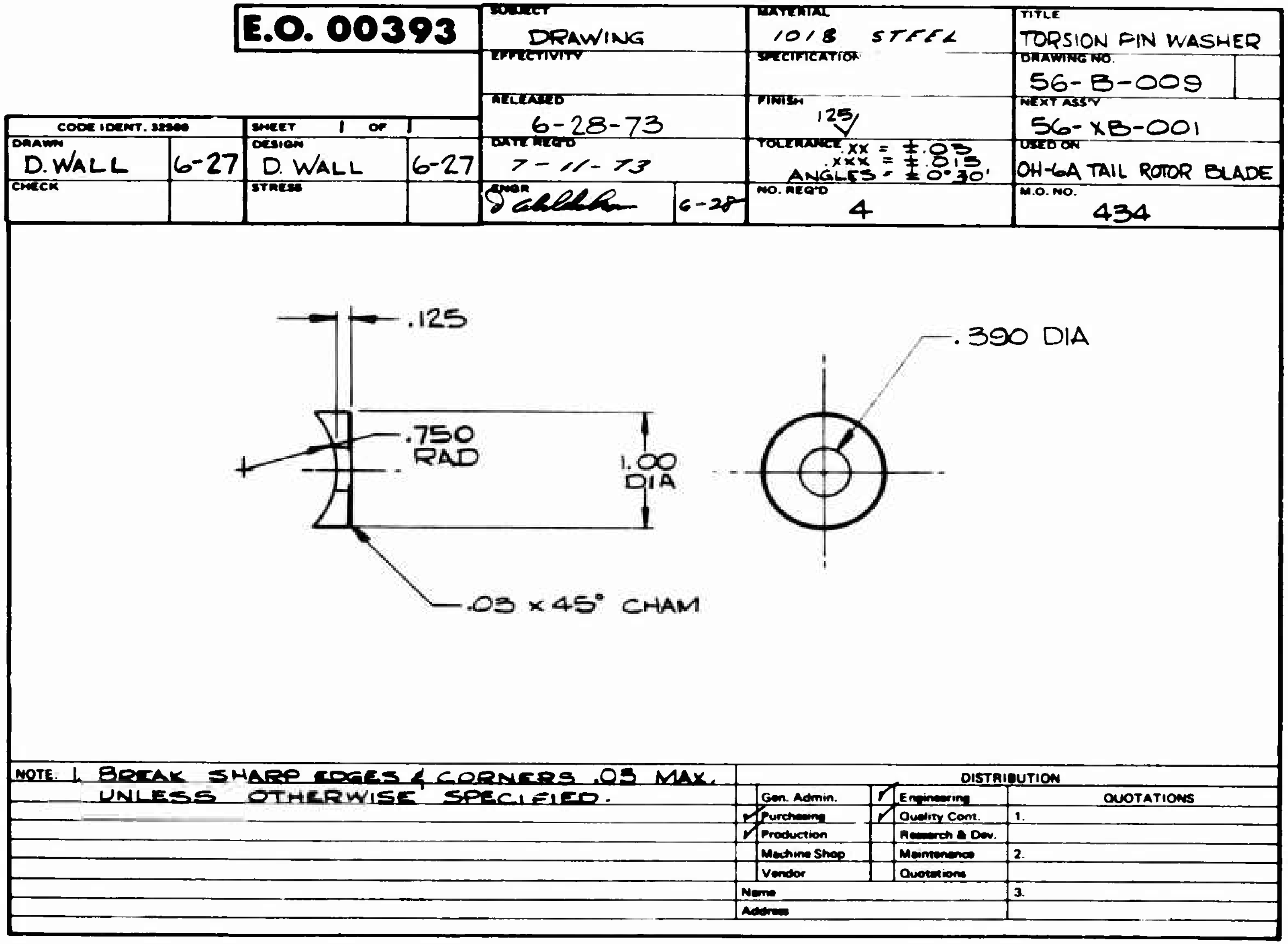
FSCS-118 ET & RT Resin System (Referenced in Dwg. 56-XB-001)



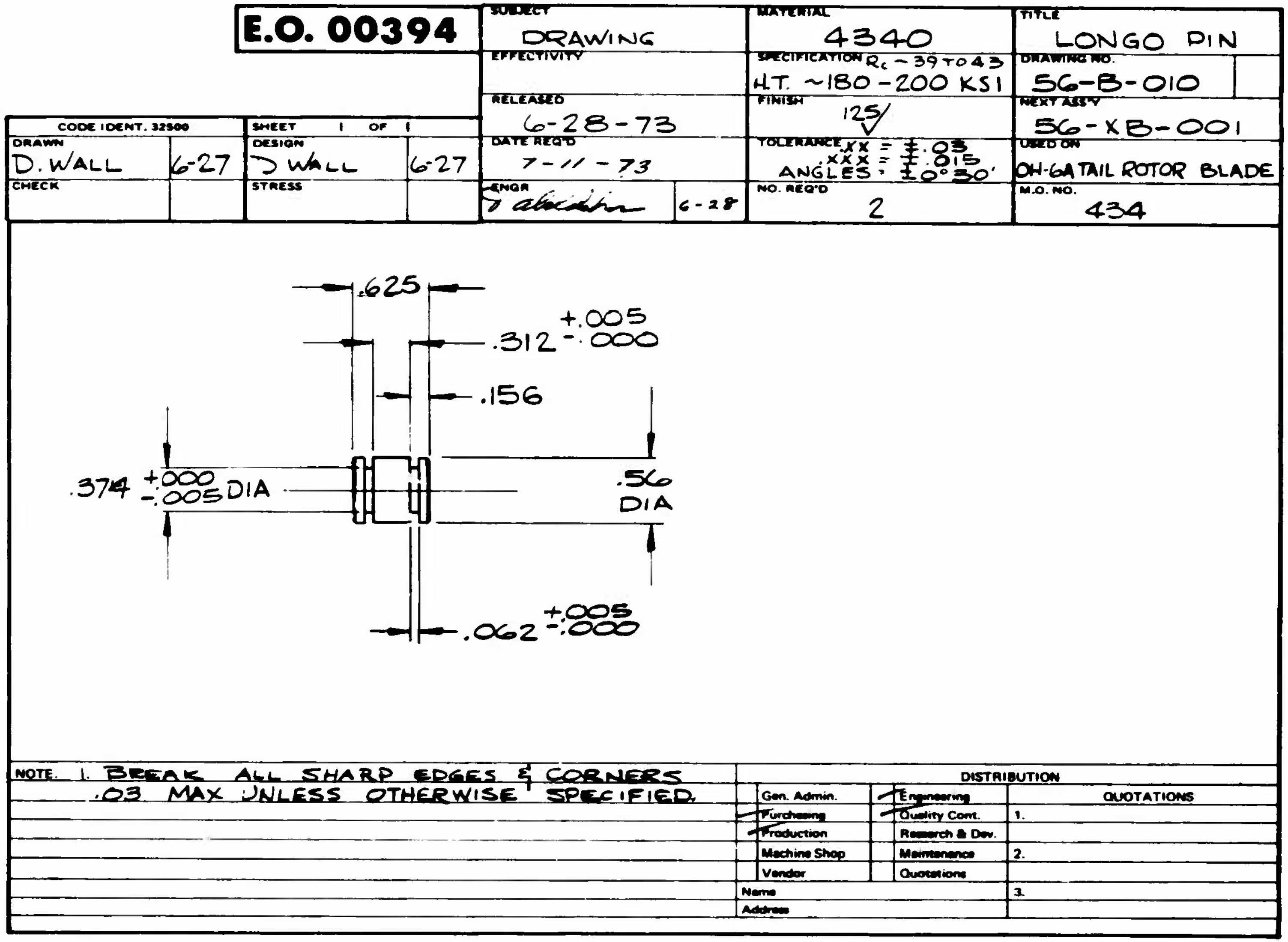
TAIL ROTOR BLADE - OH-6A HELICOPTER BLADE, Page 1 of 2



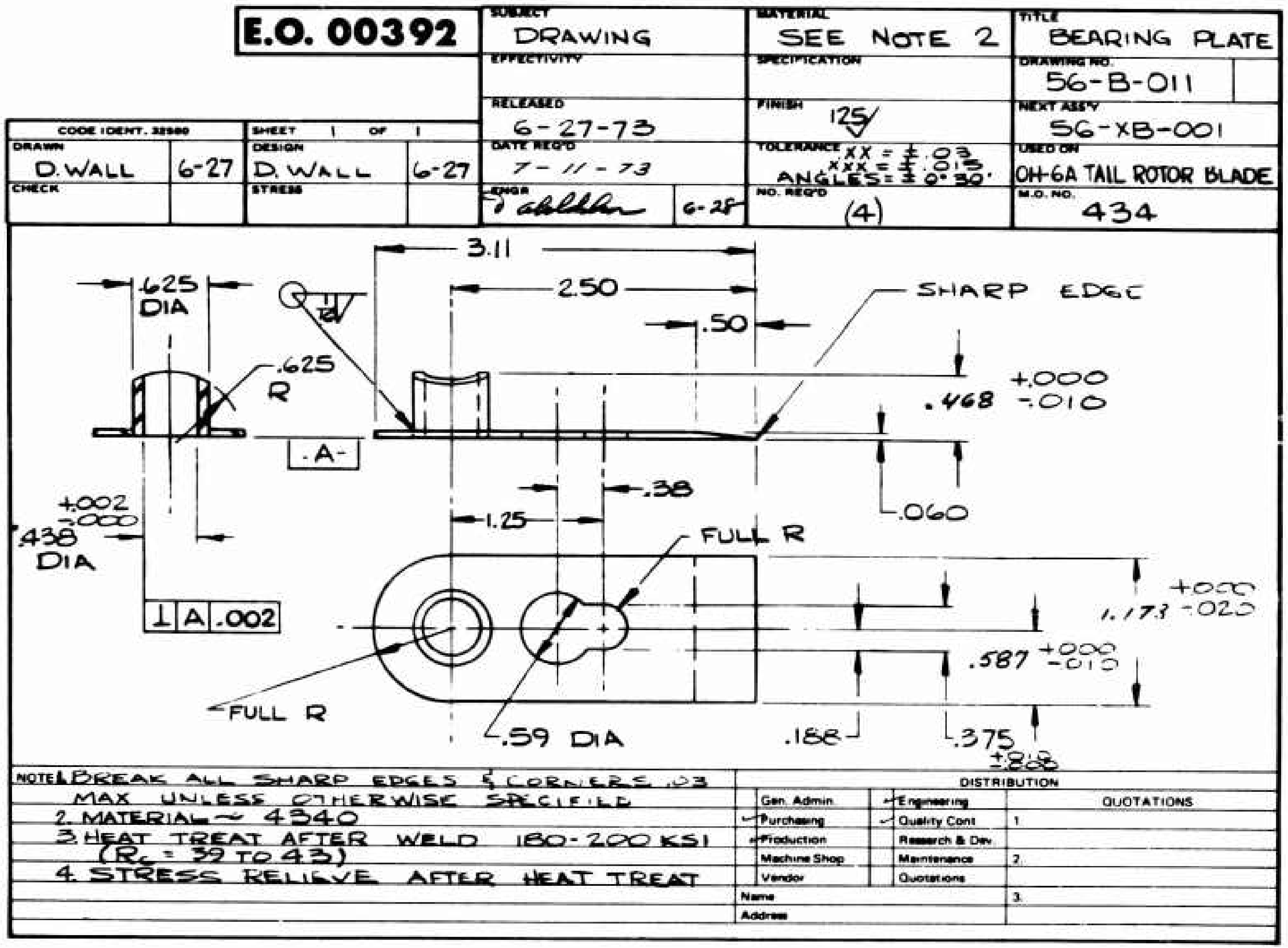
TAIL ROTOR BLADE - OH-6A HELICOPTER BLADE, Page 2 of 2



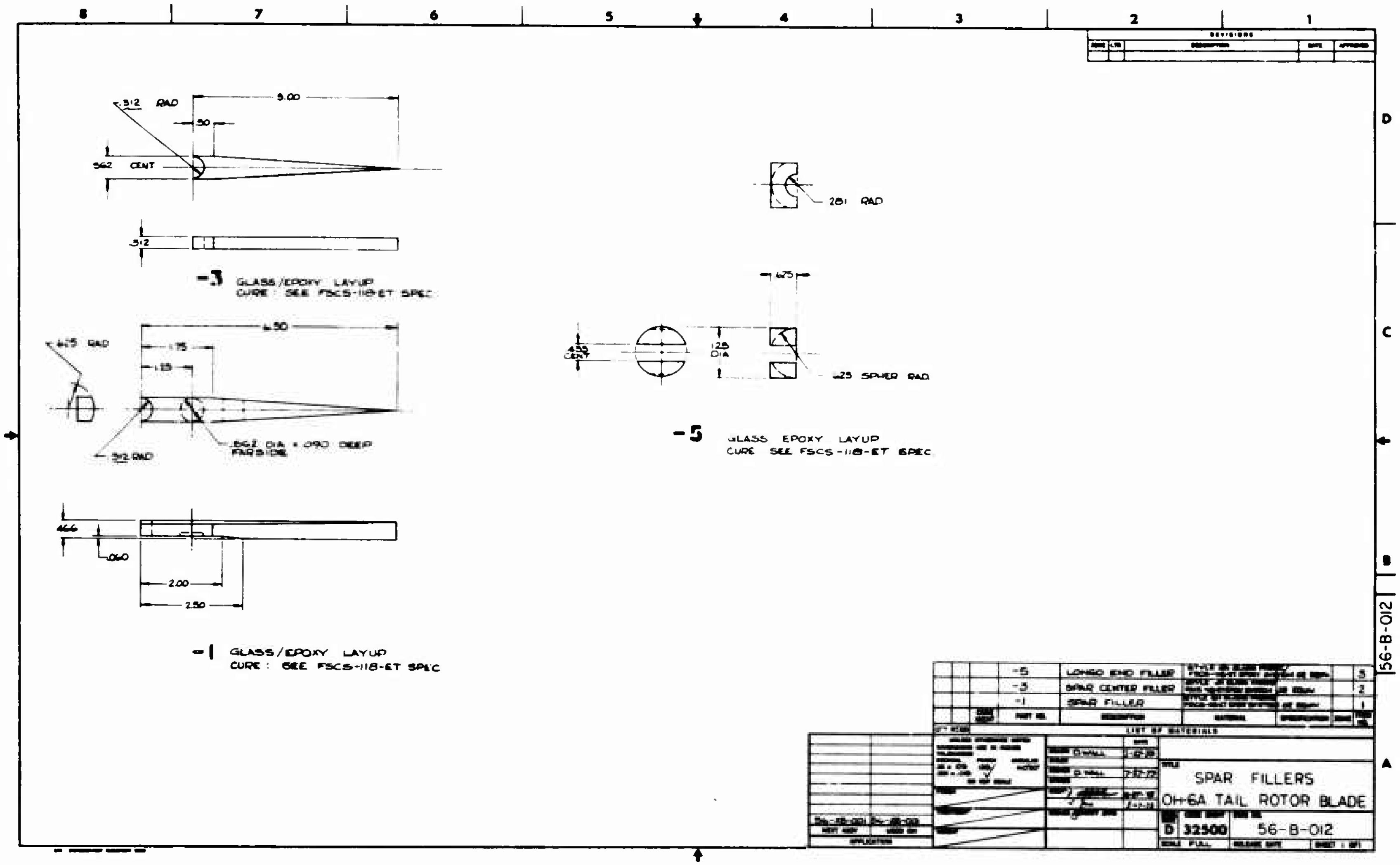
TORSION PIN WASHER


E.O. 00394
SUBJECT DRAWING
MATERIAL 4340
TITLE LONGO PIN
EFFECTIVITY
SPECIFICATION R_c ~ 39 TO 43
H.T. ~180 - 200 KSI
DRAWING NO. 56-B-010
CODE IDENT. 32500
SHEET 1 OF 1
RELEASED 6-28-73
FINISH 125
NEXT ASS'Y 56-XB-001
DRAWN D. WALL 6-27
DESIGN D WALL 6-27
DATE REQ'D 7-11-73
TOLERANCE .XX = ±.03 .XXX = ±.015 ANGLES = ±0°30'
USED ON OH-6A TAIL ROTOR BLADE
CHECK
STRESS
ENGR
6-28
NO. REQ'D 2
M.O. NO. 434
.625
.312 +.005 -.000
.156
.374 +.000 -.005 DIA
.56 DIA
.062 +.005 -.000
NOTE: 1. BREAK ALL SHARP EDGES & CORNERS .03 MAX UNLESS OTHERWISE SPECIFIED.
DISTRIBUTION
Gen. Admin.
Purchasing
Production
Machine Shop
Vendor
Engineering
Quality Cont.
Research & Dev.
Maintenance
Quotations
QUOTATIONS
1.
2.
3.
Name
Address

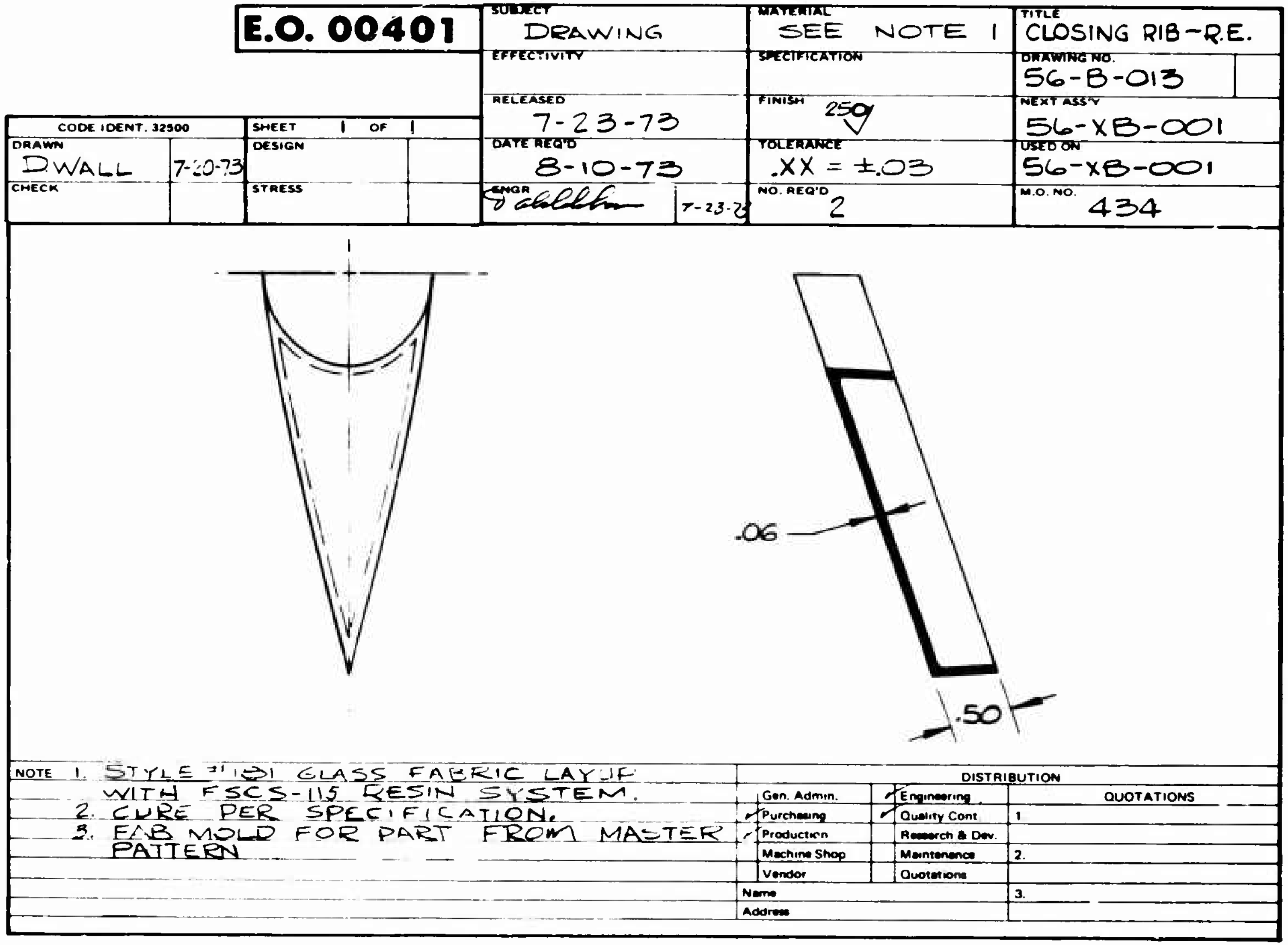
LONGO PIN



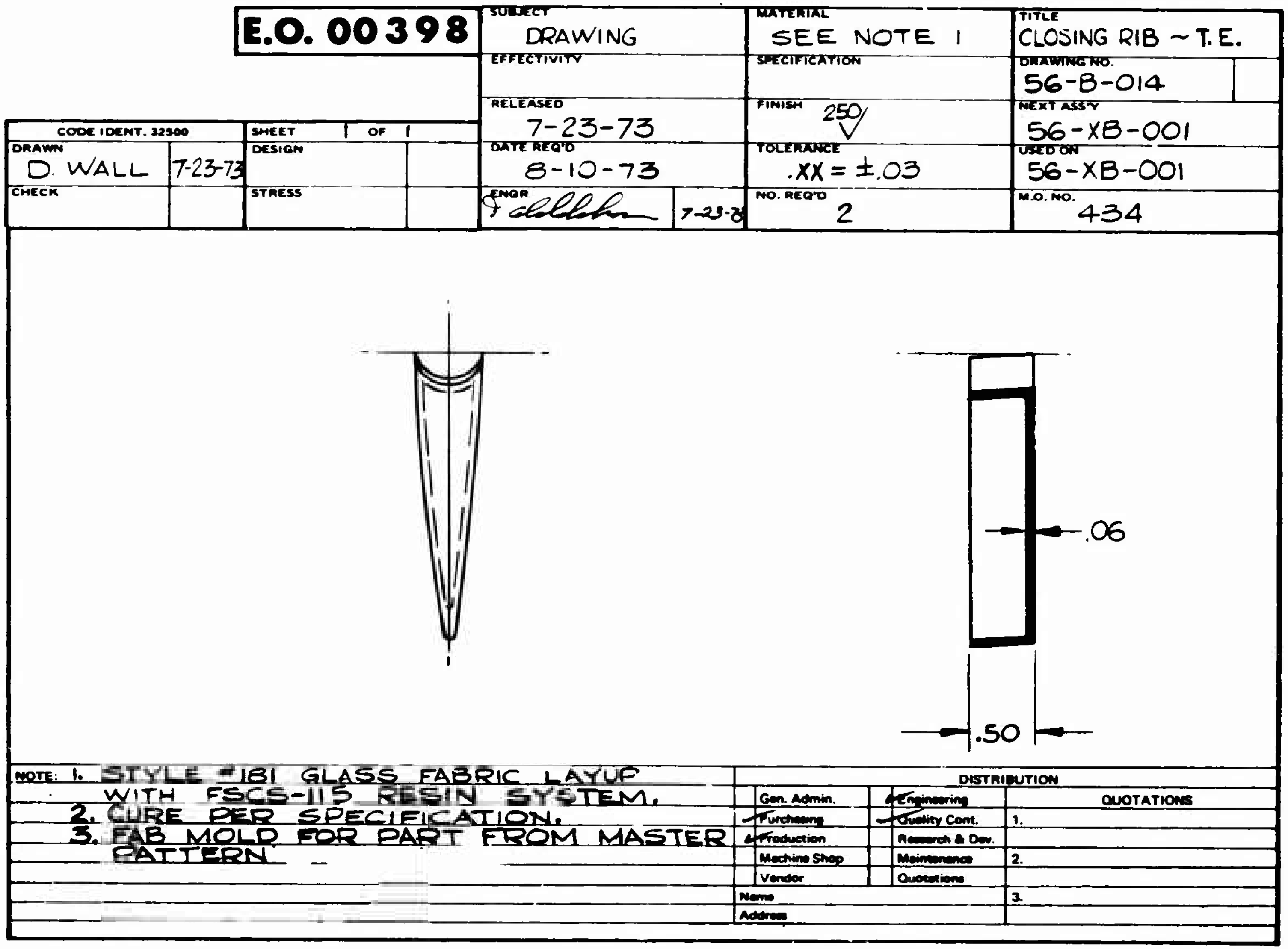
BEARING PLATE



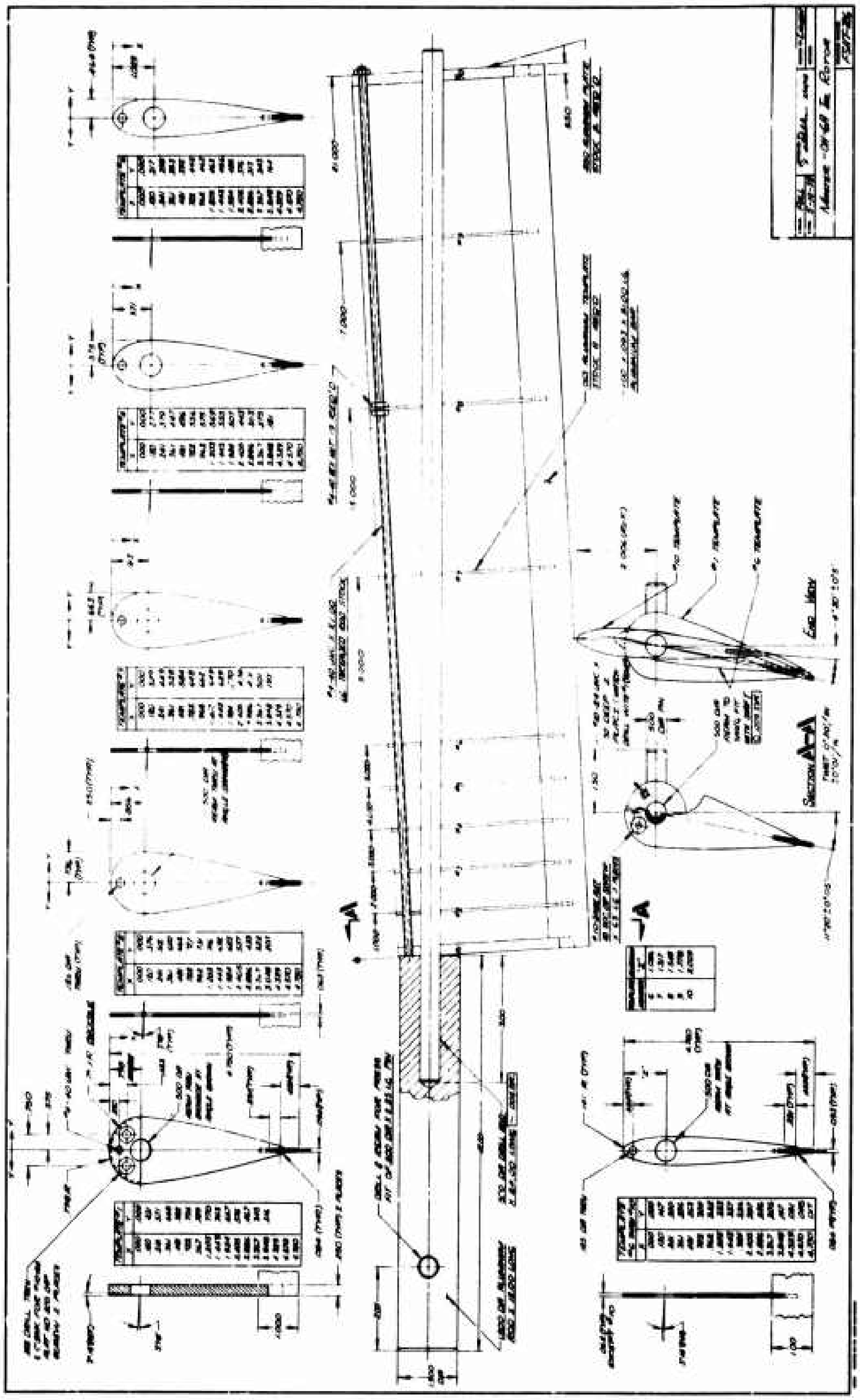
SPAR FILLERS - OH-6A TAIL ROTOR BLADE



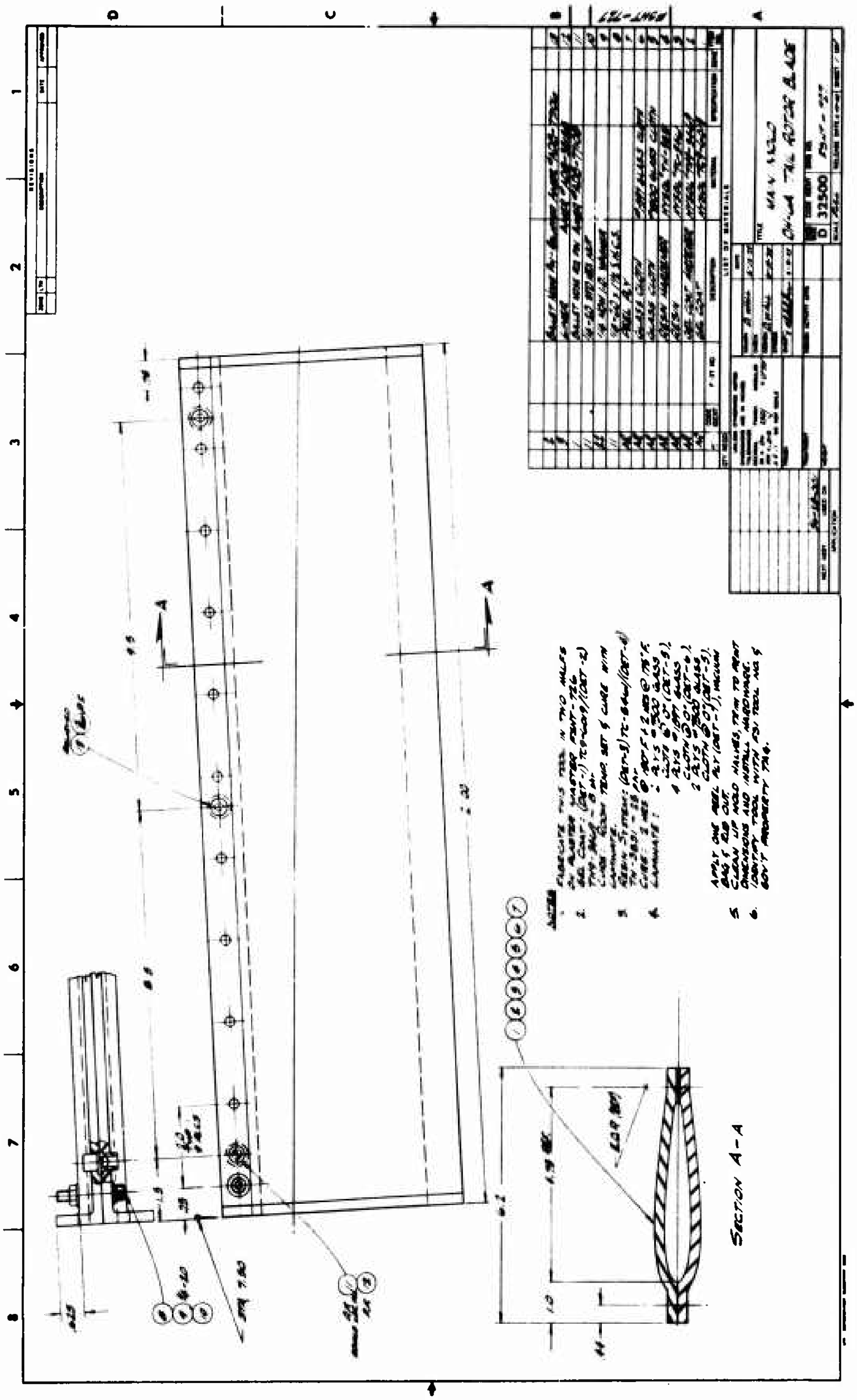
CLOSING RIB - R. E.



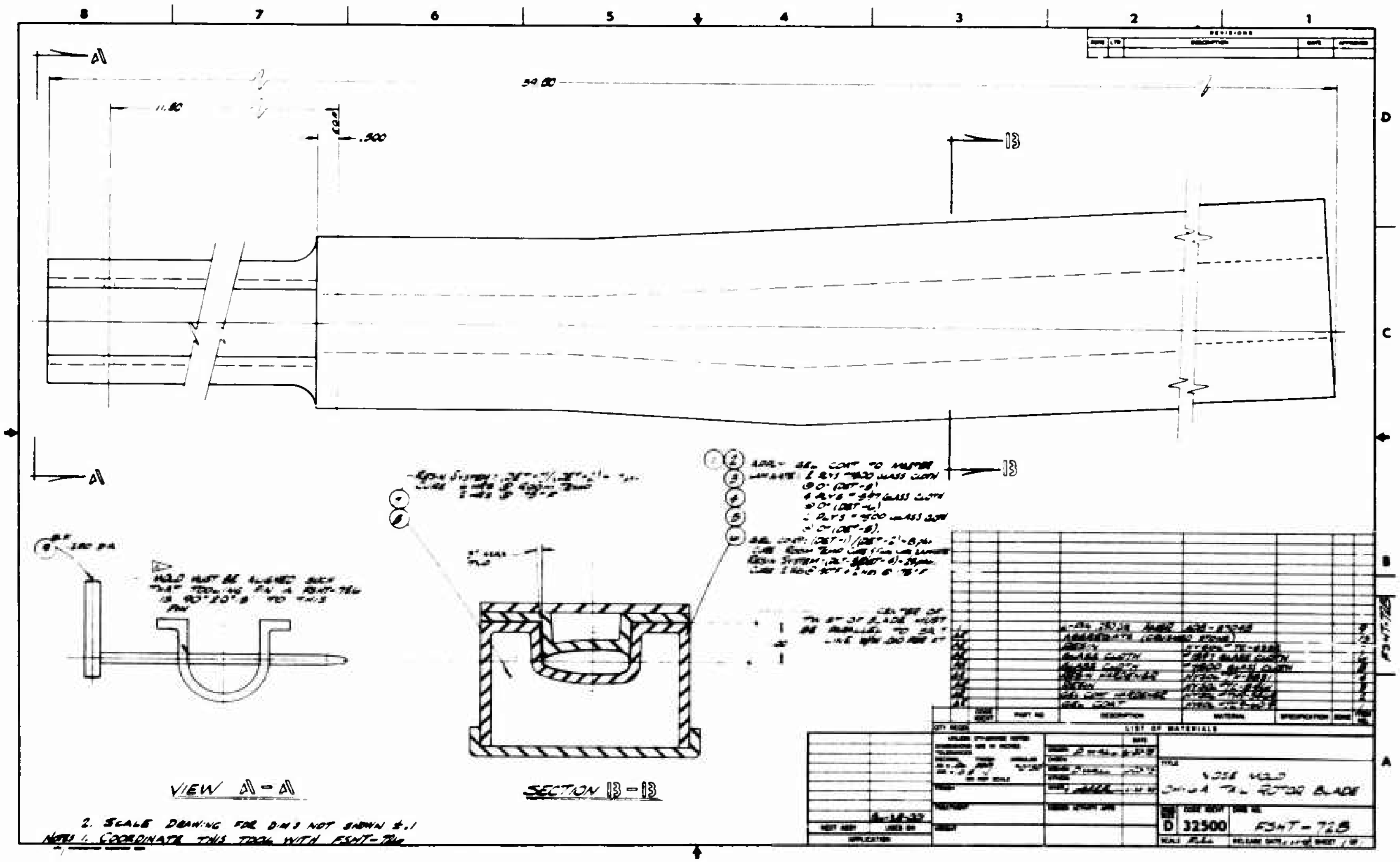
CLOSING RIB - T. E.



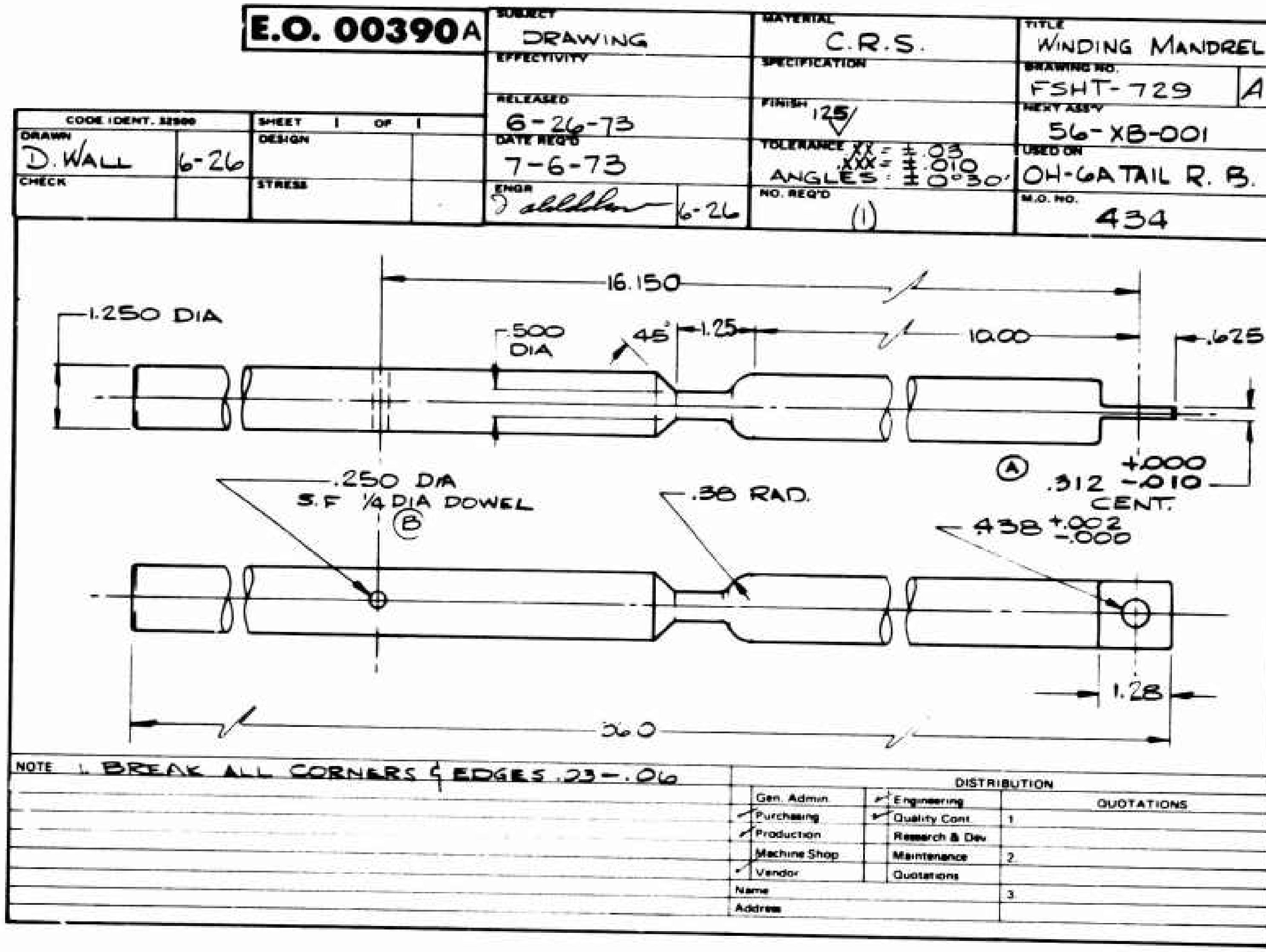
MASTER OH-6A TAIL ROTOR



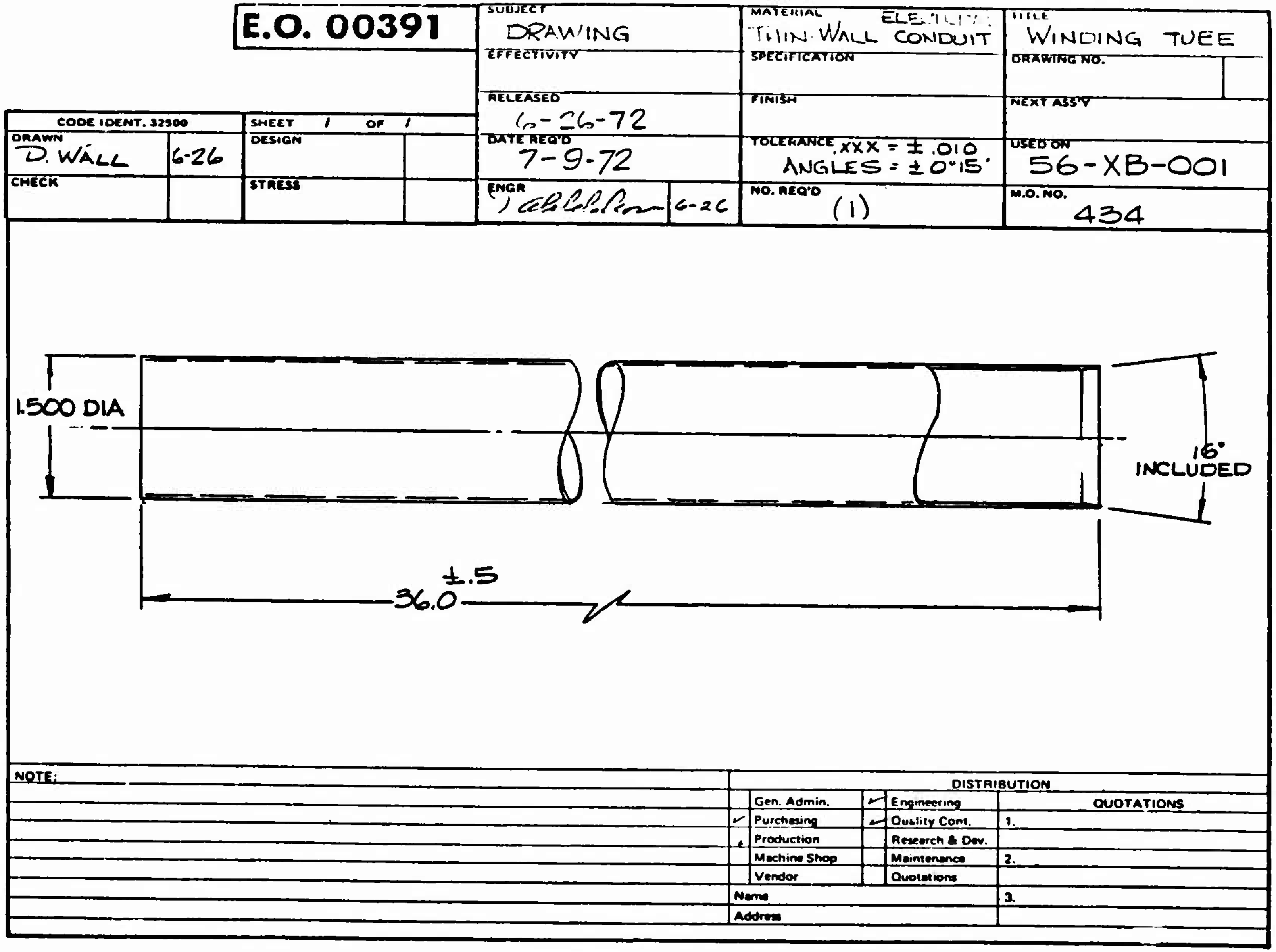
MAIN MOLD OH-6A TAIL ROTOR BLADE



NOSE MOLD OH-6A TAIL ROTOR BLADE



SPAR ASSEMBLY AND WINDING MANDREL



WINDING TUBE

CONTROL SPECIFICATION NO. FSCS-118 ET & RT

RESIN SYSTEM

1.0 DESCRIPTION

1.1 Use

1.1.1 FSCS 118 ET: A high temperature epoxy system having long pot life, low viscosity, and elevated temperature cure characteristics especially suitable for filament winding processes.

1.1.2 FSCS-118 RT: A high temperature epoxy system having short pot life, low viscosity, and room temperature set characteristics especially suitable for assembly and bonding processes.

1.2 Properties - FSCS-118 ET

1.2.1 Modulus of Elasticity (E) 450,000 psi

1.2.2 Tensile Strength - Ultimate (F_{tu}) 9,500 psi

1.2.3 Heat Distortion Temperature (HDT) 400°F

1.2.4 Density (ρ) 9.0412 lb/in.^{3}

1.2.5 Coefficient of Thermal Expansion (α) 40 x 10^{-6}in./in./°F

1.2.6 Capable of Structural Performance at 400°F

1.3 Properties - FSCS-118 RT

1.3.1 Modulus of Elasticity (E) 450,000 psi

1.3.2 Tensile Strength - Ultimate (F_{tu}) 11,000 psi

1.3.3 Heat Distortion Temperature (HDT) 400°F

1.3.4 Density (ρ) 0.0412 lb/in.^{3}

1.3.5 Coefficient of Thermal Expansion (α) 40 x 10^{-6}in./in./°F

1.3.6 Capable of Structural Performance at 400°F

1.4 Formulation

1.4.1 FSCS-118 ET

Resin	APCO 2434	100 pbw
Hardener	APCO 2347	7.5 ± .5 pbw

1.4.2 FSCS-118 RT

Resin	APCO 2434	100 pbw
Hardener	APCO 2340	27 pbw

1.5 Pot Life

Storage life or 'pot life' of the blended compound shall be as follows:

FSCS-118 ET - 24 hours minimum
FSCS-118 RT - 1 hour minimum

1.6 Shelf Life

Unopened containers have a shelf life of 24 months from date of manufacture.
Opened containers which have been resealed have a shelf life of 12 months.

2.0 SAFETY PRECAUTIONS

2.1 Personal Protection:

Avoid contact with skin, eyes, and clothing during blending of the components, mixing, and application operation. If skin is contaminated, clean off with acetone or alcohol followed by washing with soap and water. Should material get in eyes, flush with water and get prompt medical attention.

2.2 Ventilation:

Avoid breathing fumes. Blend, mix, and apply in well ventilated area. During oven cure, use well ventilated oven with exhaust air to outside of building.

3.0 MIXING AND APPLICATION

3.1 Equipment

Any suitable mixing or blending equipment may be used which will produce a smooth, workable mixture free from lumps and entrapped air. All mixing equipment shall be clean and dry before use and cleaned and dried after use.

3.2 Containers

Use only metal, glass, polyethylene, or uncoated paper containers. All containers must be clean and dry before use.

3.3 Component Status

Insure resin and hardener have not exceeded shelf life marked on containers. If shelf life has been exceeded or is not on container, do not use.

3.4 Component Weighing

Weigh components carefully to assure proper formulation in accordance with Paragraph 1.4.

3.5 Blending:

Pour the hardener into the resin and blend the mixture with an air motor and "Jiffy blade" (or equivalent) until thoroughly mixed.

4.0 CURING

4.1 Product

When system is used to make a production item, cure according to instructions in the shop traveler or applicable process specification.

4.2 FSCS-118 ET

4.2.1 Set Time:

Cure for four (4) hours at 130°F.

4.2.2 Cure:

Cure for two (2) hours at 180°F plus two (2) hours at 250°F.

4.3 FSCS-118 RT

4.3.1 Set Time:

Cure at room temperature for six (6) hours.

4.3.2 Cure:

Cure for four (4) hours at 250°F

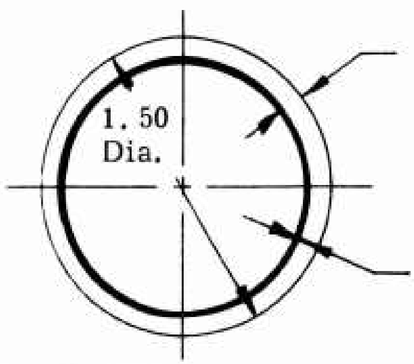
APPENDIX II

STRESS ANALYSIS

This appendix contains the stress and stiffness calculations for the OH-6A helicopter composite tail rotor blade. The analysis is based on the loads given in Hughes Tool Company, Aircraft Division, Report No. 369-5-2002, February 1966.

The blade stiffnesses are calculated at the following blade stations:

Stations 1.6 to 6.25



$$\left\{ \begin{array}{ll} E_x & = 6.059 \times 10^6 \text{ psi} \\ G & = .996 \times 10^6 \text{ psi} \\ \rho & = .0468 \times 10^6 \text{ lb/in.}^3 \end{array} \right.$$

$$\left\{ \begin{array}{ll} \text{SC-100 Fabric} & \\ \rho & = .0694 \text{ lb/in.}^3 \end{array} \right.$$

Unit Weight

$$W = \pi(.750^2 - .635^2)\,.0468 + \pi(1.260 \times .010)\ .0694$$

$$= .0262 \text{ lb/in.}$$

Spanwise stiffness

$$EA = 6.059 \times 10^6 \times \pi(.750^2 - .635^2) = 3.0318 \times 10^6 \text{ lb}$$

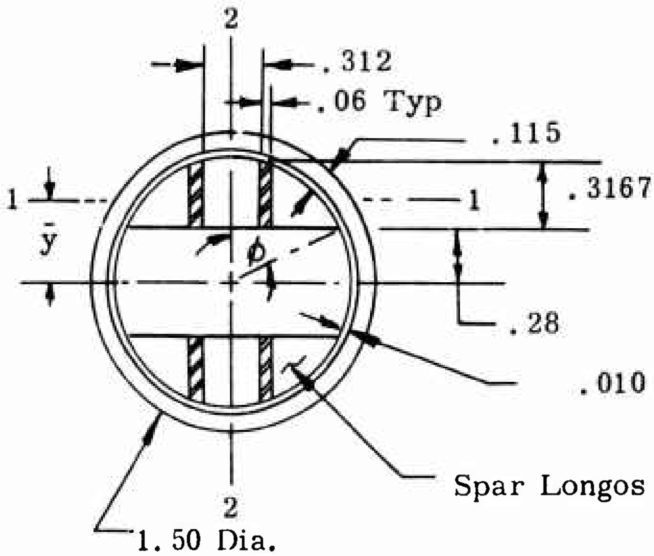
Bending stiffness (Flapwise and Chordwise)

$$EI = 6.059 \times 10^6 \times \frac{\pi}{4}(.750^4 - .635^4) = .7320 \times 10^6 \text{ lb-in.}^2$$

Torsional stiffness

$$GK = .996 \times 10^6 \times \frac{\pi}{2}(.750^4 - .635^4) = .2406 \times 10^6 \text{ lb-in.}^2$$

Station 7.5



$\left\{ \begin{array}{ll} E_x & = 6.059 \times 10^6 \text{ psi} \\ G & = .996 \times 10^6 \text{ psi} \\ \rho & = .0468 \text{ lb/in.}^3 \end{array} \right.$

SC-100 Fabric $\left\{ \begin{array}{ll} \rho & = .0694 \text{ lb/in.}^3 \end{array} \right.$

$\left\{ \begin{array}{ll} E & = 9.75 \times 10^6 \text{ psi} \\ G & = .2239 \times 10^6 \text{ psi} \\ \rho & = .0468 \text{ lb/in.}^3 \end{array} \right.$

The cross-sectional properties of one-half the spar longos are: [1]

$$\phi = \cos^{-1}\left(\frac{.28}{.625}\right) = 63.3846 \text{ deg.}$$

$$R = .625 \text{ in.}$$

$$A = \frac{R^2}{2}(2\phi - \sin 2\phi) - .06 \times 2 \times .3167 = .2377 \text{ in.}^2$$

$$\bar{Y} = R\left(\frac{4 \sin^3 \phi}{6\phi - 3 \sin 2\phi}\right) = .4219 \text{ in.}$$

$$I_1 = R^4\left[\frac{1}{8}(2\phi - \sin 2\phi)\left(1 + \frac{2 \sin^3\phi \cos\phi}{\phi - \sin\phi \cos\phi}\right) - \frac{8}{9}\left(\frac{\sin^6\phi}{2\phi - \sin 2\phi}\right)\right]$$

$$= .002277 \text{ in.}^4$$

$$I_2 \approx R^4\left\{\frac{1}{8}(2\phi - \sin 2\phi) - \frac{1}{12}\left[\frac{(2\phi - \sin 2\phi)\sin^3\phi\cos\phi}{\phi - \sin\phi\cos\phi}\right]\right\}$$

$$\approx .018780 \text{ in.}^4$$

Roark, R. J., FORMULAS FOR STRESS AND STRAIN, New York, McGraw-Hill Book Co. Fourth Edition, p. 75

Calculate the torsional shape factor "K" assuming rectangular shape .90 x .30, a = .45, b = .15

$$K = ab^3 \left[\frac{16}{3} - 3.36 \frac{b}{a} (1 - \frac{b^4}{12a^4})\right] = .006401 \text{ in.}^4$$

The cross-sectional properties of the spar are the same as at Stations 1.6 to 6.25:

$$A = \pi(.750^2 - .635^2) = .5004 \text{ in.}^2$$

$$I = \frac{\pi}{4}(.750^4 - .625^4) = .1208 \text{ in.}^4$$

$$K = 2I = .2416 \text{ in.}^4$$

The cross-sectional properties of the spar longos and spar material at Station 7.5 are:

<u>Unit Weight</u>

$$W = (2 \times .2377 + .5004)\ .0468 + \pi(1.260 \times .010)\ .0694$$
$$= .0484 \text{ lb/in.}$$

<u>Spanwise Stiffness</u>

$$EA = (2 \times .2377 \times 9.750 + .5004 \times 6.059)\ 10^6 = 7.667 \times 10^6 \text{ lb}$$

<u>Flapwise Bending Stiffness</u>

$$EI_{fl} = \left[9.750\ (.2377 \times .4219^2 + .002277)^2 + 6.059 \times .1208\right] 10^6$$
$$= 1.014 \times 10^6 \text{ lb-in.}^2$$

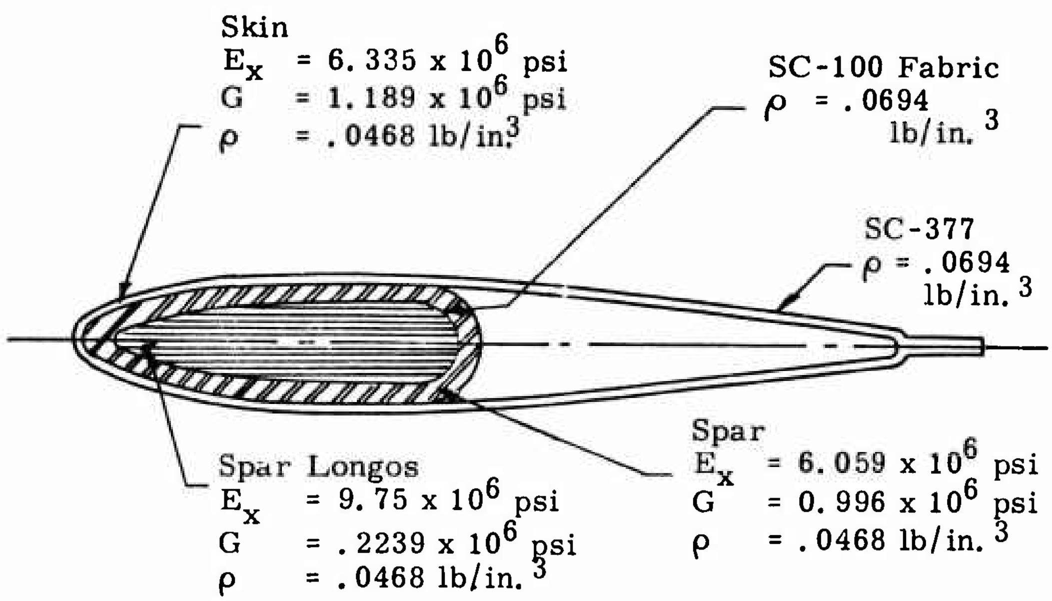
<u>Chordwise Bending Stiffness</u>

$$EI_{ch} = \left[9.750 \times 2 \times .018780 + 6.059 \times .1208\right]\ 10^6$$
$$= 1.0981 \times 10^6 \text{ lb-in.}^2$$

<u>Torsional Stiffness</u>

$$GK = \left[.2239 \times 2 \times .006401 + .996 \times .2416\right] 10^6$$
$$= .2435 \times 10^6 \text{ lb-in.}^2$$

Stations 12.75 to 25.49



The cross-sectional properties of the skin, spar plus spar core, and spar core are calculated by the computer. The properties for the components making up the blade are:

Property	Skin	Spar Plus Spar Longos	Longos	Radar absorbers
CG*, in.	2.3954	1.1814	1.2186	2.0289
A, in.^{2}	.3733	.9565	.4614	.1376
I_{xc}, in.^{4}	.0197	.0222	.0031	-
I_{yo}, in.^{4}	.7097	.2900	.0953	-
K, in.^{4}	.0645	.0903	.0131	-

* Measured from leading edge of blade.

Unit Weight

$$W = (.3733 + .9565)\ .0468 + .1376 \times .0694 = .0718 \text{ lb/in.}$$

Center of Gravity

$$CG = \left[(.3733 \times 2.3954 + .9565 \times 1.1814)\ .0468 + .1376 \times 2.0289 \times .0694\right] \div .0718 = 1.5892 \text{ in.}$$

Spanwise Stiffness

$$EA = \left[(.3733 \times 6.335) + (.9565 - .4614)\ 6.059 + (.4614 \times 91750)\right]10^6$$
$$= 9.8633 \times 10^6 \text{ lb}$$

Flapwise Bending Stiffness

$$EI_{fl} = \left[.0197 \times 6.335 + (.0222 - .0031)\ 6.059 + .0031 \times 9.750\right]10^6$$
$$= .2708 \times 10^6 \text{ lb-in.}^2$$

Neutral Axis Location

$$\bar{x} = \left[.3733 \times 2.3954 \times 6.335 + .9565 \times 1.1814 \times 6.059 + (9.750 - 6.059)\ .4614 \times 1.2186\right]10^6 \div \left[9.8633 \times 10^6\right]$$
$$= 1.4789 \text{ in.}$$

Chordwise Bending Stiffness

$$EI_{ch} = \left[.7097 + .3733\ (1.4789 - 2.3954)^2\right] 6.335 \times 10^6 + \left[.2900 + .9565\ (1.4789 - 1.1814)^2\right] 6.059 \times 10^6 + \left[.0953 + .4614\ (1.4789 - 1.2186)^2\right] (9.750 - 6.059)\ 10^6$$
$$= 9.2195 \times 10^6 \text{ lb-in.}^2$$

Torsional Stiffness

$$GK = \left[.0645 \times 1.189 + .0903 \times .996 + (.2239 - .9960)\ .0131\right]10^6$$
$$= .1565 \times 10^6 \text{ lb-in.}^2$$

The maximum stresses (ultimate loads) are calculated at the following locations:

Spar Core (longos) at Station 7.5

The spar core must carry the full CF loading in the attachment area.

$A = 2 \times .2377 = .4754$ in.^{2} (Reference page 54)

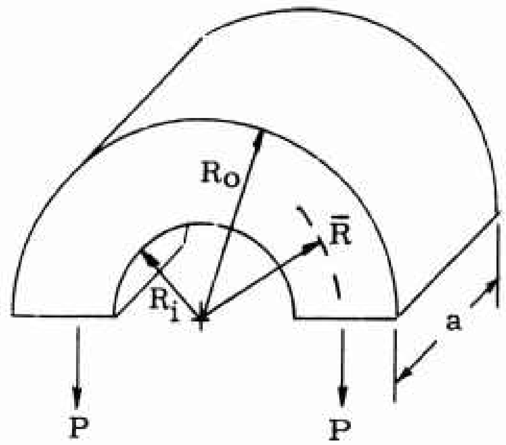
CF= 8096 lb (limit)

$$\sigma = K\left(\frac{CF}{A}\right)$$

The stress concentration factor "K" applied to the inside fibers is arrived by the following:

<u>Average Stress Due to Load P</u>

$$\sigma = \frac{P}{a(R_o - R_i)}$$



Inside fiber stress relative to average (mid-wall) fiber stress

$$\sigma_i = \sigma\left(\frac{\bar{R}}{R_i}\right)$$

$$\bar{R} = \frac{R_o + R_i}{2}$$

$$\sigma_i = \frac{P}{a(R_o - R_i)}\left(\frac{R_o + R_i}{2\ R_i}\right)$$

Stress concentration factor

$$K = \frac{\sigma_i}{\sigma} = \frac{\dfrac{P}{a(R_o - R_i}\left(\dfrac{R_o + R_i}{2\ R_i}\right)}{\dfrac{P}{a\ (R_o - R_i)}} = \frac{R_o + R_i}{2\ R_i}$$

$$K = \frac{.625 + .280}{2 \times .280} = 1.6161$$

$$\sigma = 1.6161\ \left(\frac{8096}{.4754}\right) = 27,521 \text{ psi}$$

The endurance limit for Kevlar 49/epoxy is estimated at 27% of its single cycle strength.

$$F_{all} = .27 \times 200,000 = 54,000 \text{ psi}$$

$$MS = \frac{54,000}{27,521} - 1 = .96$$

<u>Spar at Station 7.5</u>

The spar must carry the full bending loads in the attachment area.

$$\left.\begin{array}{l} M_{fl} = 3450 \text{ in.-lb} \\ M_{ch} = 1820 \text{ in.-lb} \end{array}\right\} \text{Limit}$$

Combining M_{fl} and M_{ch} vectorially

$$M = \sqrt{3450^2 + 1820^2} = 3900 \text{ in.-lb}$$

$$\left.\begin{aligned} V &= \frac{3900}{2.775} = 1405 \text{ lb} \end{aligned}\right\} \text{Limit}$$

$$\sigma = \frac{3900 \times .75}{\frac{\pi}{4}(.750^4 - .635^4)} = 24,212 \text{ psi}$$

$$F_{all} = .27 \times 121,100 = 32,697 \text{ psi}$$

$$MS = \frac{32,697}{24,212} - 1 = .35$$

$$\tau = \frac{1405 \times 2}{\pi(.750^2 - .635^2)} = 5615 \text{ psi}$$

$$F_{all} = .27 \times 25,000 = 6750 \text{ psi}$$

$$MS = \frac{6750}{5615} - 1 = .20$$

Skin at Station 12.75

The maximum stresses in the skin are calculated using the loads at Station 11.6 and assuming the loads are distributed in the blade in accordance with the components' stiffness.

$$\left.\begin{aligned} M_{fl} &= 1365 \text{ in.-lb} \\ M_{ch} &= 294 \text{ in.-lb} \\ CF &= 7972 \text{ lb} \end{aligned}\right\} \text{Limit}$$

$$\sigma = \frac{M_{fl} \times C \times E_{sk}}{\epsilon\, EI_{fl}} + \frac{CF \times E_{skin}}{\epsilon\, AE}$$

$$\sigma = \frac{1365 \times .3367 \times 6.335 \times 10^6}{.2708 \times 10^6} + \frac{7972 \times 6.335 \times 10^6}{9.8633 \times 10^6}$$

$$= 10,752 + 5120 = 15,872 \text{ psi}$$

$F_{all} = .27 \times 81,900 = 22,113$ psi

$$MS = \frac{22,113}{15,872} - 1 = .39$$

SYMBOLS

A	Area (in.^{2})
AS	Skin cross-sectional area (in.^{2})
a	Dimension (in.)
b	Dimension (in.)
CF	Centrifugal force (lb)
CG	Distance from leading edge to center of gravity (in.)
c	Dimension (in.)
DA	Double amplitude (in.)
E	Modulus of elasticity (psi)
EA	Spanwise stiffness (lb)
EI	Bending stiffness (lb-in.^{2})
ES	Skin modulus of elasticity in the spanwise direction (psi)
F	Allowable stress (psi)
G	Shear modulus of elasticity (psi)
GK	Torsional stiffness (lb-in.^{2})
GS	Skin shear stiffness (lb-in.^{2})
I	Cross-sectional moment of inertia (in.^{4})
K	Torsional constant (in.^{4})
L	Skin midwall perimeter (in.)
M	Moment (in.-lb)
MS	Margin of safety = $\frac{\text{allowable stress}}{\text{actual stress}} - 1$
R	Radius (in.)
TS	Skin thickness (in.)
V	Volume ratio, shear load (lb)
W	Unit weight (lb/in.)
X	Coordinate (in.)
Y	Coordinate (in.); dimension (in.)
α	Winding angle (deg)
μ	Poisson's ratio
ρ	Density (lb/in.^{3})
σ	Unit stress (psi)
τ	Unit shear stress (psi)
ϕ	Angle (deg)

Subscripts

all	allowable
ch	chordwise direction
c	composite
cu	compression ultimate
fl	flapwise direction
f	fiber
i	inside
o	outside
r	resin
tu	tension ultimate
x	spanwise direction
xo	x axis about center of gravity

xy	spanwise and chordwise directions 'shear'
y	chordwise direction
yo	y axis about center of gravity
1	axis 1, 1
2	axis 2, 2
//	direction parallel to fibers
$\perp$	direction normal to fibers

Superscripts

-	center of gravity